SHARMA • PRASAD • SINGH

A TEXT BOOK OF Practical PHYSICS

BHARATI BHAWAN

A Text Book of Practical Physics

(For B.Sc. Students)

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PREFACE

(Fourth Edition)

The present edition is the outcome of a thorough revision and enlargement of the previous edition. The book has been made up-to-date in the light of the recent courses of studies for B.Sc. examinations of various universities for students taking the examinations at pass standard.

Suggestions for further improvement in the materials of the book will be most welcome.

January, 1986 AUTHORS

(First Edition)

The present book covers the courses of study of practical Physics of B. Sc. classes. Several books of practical Physics intended for students of B. Sc. classes are available but the present book has been written specially to incorporate the recent changes in the courses of study, and to provide guidance for the types of experiments which the students are required to perform during practical examinations.

The special feature of the present book is that it deals with a wide variety of associated experiments in addition to the prescribed experiments. Numerous notes, hints, discussions and precautions have been added to the experiments described in the text to facilitate the understanding of the underlying ideas for performing the experiments successfully. Care has been taken to discuss the theory of the experiments in detail, so that the experimentor may not feel that he is performing an experiment mechanically.

The book is the outcome of the experiences of the authors in their capacity as teachers and examiners in a University, and the authors believe that material of the book will not only serve the students in their practical classes and for preparing for practical examinations but it will also be useful to those who take up the teaching of Physics as a career after taking postgraduate degrees.

Several colleagues have helped us in many ways during the preparation of the manuscript. Their kind help is being gratefully acknowledged. We are indebted to Dr. S. C. Prasad, Professor of Physics and Dean of the Faculty of Science, University of Bihar, for the kind encouragement which we have received from him.

Our efforts will be fruitful only if the book serves the best interest of those for whom it has been written. We request our readers that they should kindly draw our attention towards the errors and ommissions, and make suggestions for the improvement of the book.

March, 1968 AUTHORS

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INTRODUCTION

Errors in observation. Laboratory work in Physics involves the use of apparatus to make measurement which can be used either to make a definite determination—such as the specific heat of iron, etc.—or to investigate the validity of a law. In fact, physics is the science of accurate measurements. All measurements taken during an experiment are subject to the errors which might be (i) *random errors*, (ii) *systematic errors*.

Random error arises due to the incorrect judgement of the observer in taking different observations and small changes in the experimental conditions during the progress of the experiment. If random errors are only due to chance but not to any personal bias of the observer, then they are evenly distributed on both sides of the true value. Hence random errors can be minimised *by taking several readings caerfully and methodically and then taking their arithmetical mean. So it is necessary to repeat the same observations a number of times.*

Systematic error arises out of faulty or incorrectly adjusted instruments, mistakes on the part of the observer in reading a scale, recording a number or other similar effects. Its effect is to make the readings systematically greater or smaller than the true reading. Systematic errors can be eliminated once their source is known and the rule governing them is known.

All instrumental errors, radiation loss or gain in calorimetric experiments, the error due to end effect in the determination of velocity of sound in air by resonance column method, etc. belong to this category.

When the source of systematic error is not known, it is advisable to check its presence by repeating the observations under altered experimental conditions.

The determination of errors. There are different procedures for the determination of error expected in the computed mean value of the quantity to be measured, depending on what definition of errors is used. This gives a measure of the reliability of the determined value.

The average error η is the arithmetic mean of all the error *neglecting their signs.* If $x_1, x_2, x_3, \ldots\ldots, x_n$ are the values of n different observations of the same physical quantity p, the arithmetic mean being x, then the *deviations* (or residuals) are

$$\delta_1 = x_1 - x,\ \delta_2 = x_2 - x,\ \delta_3 = x_3 - x,\ \ldots\ldots,\ \delta_n = x_n - x.$$

These deviations are taken to represent the errors, so that for a large number of observations the average error is given by

$$\eta = \pm \frac{\Sigma\delta}{\sqrt{n(n-1)}} \cong \pm \frac{\Sigma\delta}{n}.$$

The root-mean-square error (or standard deviation) μ is the square root of the average of the squares of the errors and is given by

$$\mu = \pm \sqrt{\frac{\Sigma\delta^2}{\sqrt{n(n-1)}}} \cong \pm \sqrt{\frac{\Sigma\delta^2}{n}}.$$

The probable error r is that error for which half of the total errors lie below it and half above it, and from theory of probability it is given by

$$r = \pm 0{\cdot}6745 \sqrt{\frac{\Sigma\delta^2}{\sqrt{n(n-1)}}}$$

$$= \pm 0{\cdot}6745\,\mu = \pm 0{\cdot}8453\,\eta.$$

These formulae are valid when the *number of observations is large and free from systematic errors and personal bias.*

Example :

Different values of focal length of a lens (cm)	Arithmetic mean (cm)	Deviations	Σ δ	Σ δ²	Average error η	Root-mean-square error μ	Probable error r
15·17	15·19	−0·02	0·06	0·001	0·013	0·015	0·01
15·19		0					
15·20		+0·01					
15·18		−0·01					
15·21		+0·02					

It is important to note that various errors quoted above are of the same order of magnitude. Also the probable error and root-mean-square error lose much of their quantitative significance when the number of observations is *not* very large. Hence it is justifiable to select the *average error* for practical purpose and write the result as $15{\cdot}19 \pm 0{\cdot}013$ cm.

Hence the physical quantity p is given by

$$p = x \pm \eta.$$

If quantities are *added* or *subtracted*, the error of the result is the *sum* of the errors of each quantity concerned. If *multiplication* or *division* is used, the actual errors must be converted to *percentage errors* and these *percentage errors added.*

The degree of accuracy of measurements. When an experiment is made in which the measurements of various quantities are involved, it is essential to note with what accuracy each quantity can be determined with the available apparatus. In the consideration of degree of accuracy with which the various measurements in an experiment should be made, a *sense of proportion is required.* It is often unnecessary to make every measurement to the highest degree of accuracy attainable with the apparatus used. The capabilities of each component used should be considered, and the degree of accuracy of the final result will not be greater than that of the last reliable instrument used.

To see it mathematically, let us take a physical quantity p which depends on x, y and z in the way given by the equation

$$p = A\, x^{l}\, y^{-m}\, z^{n} \qquad \text{.. (1).}$$

Let δx, δy and δz be the expected small errors in the measurements of the quantities x, y and z respectively, so that the error in p, by the use of these observed quantities, is δp. Then the proportional error in p is $\dfrac{\delta p}{p}$.

Taking natural logarithm of eqn. (1), we get

$$\ln p = \ln A + \ln x - m \ln y + n \ln z \qquad \text{.. (2).}$$

Taking now the partial differentiation of eqn. (2), we get

$$\frac{\delta p}{p} = l\frac{\delta x}{x} - m\frac{\delta y}{y} + n\frac{\delta z}{z} \qquad \text{.. (3).}$$

The values of δx, δy and δz may be *positive* or *negative* and in some cases the terms on the right hand side of eqn. (3) may counteract one another. It is necessary to consider the worst case in which all the errors tend in the same sense (here $+\delta x$, $-\delta p$, $+\delta z$) giving for the error δp the maximum value, so

$$\left(\frac{\delta p}{p}\right)_{max} = l\frac{\delta x}{x} + m\frac{\delta y}{y} + n\frac{\delta z}{z} \quad \ldots \quad (4),$$

where $\frac{\delta x}{x}$, $\frac{\delta y}{y}$ and $\frac{\delta z}{z}$ denote the proportional errors in the measurement of respective quantity.

When proportional error is multiplied by 100, it gives the *percentage error*, as $\frac{\delta p}{p} \times 100$ gives the percentage error of the physical quantity p.

Hence it is advisable to measure (i) the *quantity having the highest power with higher precision than the rest* and (ii) *the smallest quantity involved in formula with greater precision.*

Rejection of observations. The chance of committing an error greater than five times the probable error in a single measurement is less than 1 in 1000; and hence this may be taken to be the maximum permissible error. So it is advisable *to reject those observations which deviate by more than five times the average error from the mean value.*

Numerical Calculation. The results of an experiment should be calculated to a degree of accuracy merited by the observations. In order to save much labour in arithmetical calculations, it is advisable to cut down suitably the number of significant figures in the result at each stage in the calculation before dealing the next stage of the calculation. Generally, four-figure logarithmic tables will give the results with sufficient accuracy. Such tables can be relied upon to an accuracy of about 1 in 2500.

In the physical measurements, if the last significant figure is zero, it must be retained in the result though it is after the decimal. Its retention denotes that accuracy is claimed to that number of significant figures. If the quantities considered are very *large* or very *small*, they should be written as a *multiple of powers of ten*. For example, 380000 may be written as $3{\cdot}8 \times 10^5$ and $0{\cdot}00039$ as $3{\cdot}9 \times 10^{-4}$, if accuracy of 1 part in 40 is claimed.

In general, all measurements should be expressed in a phrase of two parts : (i) the pure number which is the measure of the quantity in terms of the unit employed, and (ii) the unit according to the nature of the quantity.

Graphs. A graph is a pictorial representation in the form of a line, straight or curved, on squared paper, which shows the variation of one quantity with respect to another.

Practical Points for graphs. (1) Plot the *dependent variable as ordinate* on the y-axis and the *independent variable as abscissa* on the x-axis.

(2) In general practice, the origins of the two variables should be zero. There are, however, cases where this is not convenient. In that case, first select the minimum values of the data of the two variables. Then the nearest round numbers less than these minimum values should be taken as orgins for the two variables. The values of the origins of the two variables need not be equal. But be exceedingly careful when calculating gradients and constants in these cases.

(3) As far as possible choose scales for x and y which are suitable in that the actual angle (not necessarily the 'gradient') which the line makes with the axis lies between 30° and 60° and which utilize the maximum portion of the squared paper. To do so, first determine the nearest round numbers slightly greater than the maximum data of the two variables. Divide the difference between this maximum round number and the value of the origin along the axis, by the number of smallest divisions available along that particular axis. Then a simple number approximately equal to the quotient will give the value of one small division along that axis. Similarly do for other axis. It should be also noted that wherever possible, the smallest division should represent the unit of last significant figure up to which accuracy is claimed in the result, else the graph loses its significance.

(4) Then put the values after each 10 small divisions of the squared paper. This should be done for both axes. Also label your axes with the quantities plotted along them and the units in which they are measured.

(5) Locate the points on the graph by small dots in the correct position, with small circles round them.

(6) If the graph is a straight line, draw the line with the help of a scale so that it passes through as many points as possible. Other points lying outside the straight line should be evenly distributed on both sides of the straight line. Points lying far-off the graph may be rejected.

If the graph is not a straight line, draw a number of short lines here and there among the points, where it is judged the curve should be. Produce them bit by bit till a continuous curve is obtained.

(7) Give a title to the graph. Deductions made from the graph should appear either on it or very near it.

(8) To obtain a good graph, take sufficiently large number of observations.

(9) Wherever possible the straight-line graph should be used. This more accurately drawn, and deductions from such a graph are more reliable, than with curved graphs. If the relationship between the two variables is not a simple linear one, it is usually possible to obtain the straight-line form by plotting powers of one or other (or both) of the variables.

Shape of the graph. The shape of the graph depends on the relation between the two variables, x and y.

(i) If the relation is like $y=mx+c$, where m and c are constants, then the shape of the graph will be straight line.

(ii) If the relation is like $y^2=4a(x-c)$, where a and c are constants, then the shape of the graph will be a parabola.

(iii) If the relation is like $xy=k$, where k is a constant, then the shape of the graph will be rectangular hyperbola.

Interpolation and Extrapolation. If the value of one quantity, say x, be given, then the corresponding value of the other quantity, y, can be easily determined from the graph. First mark the given value of x on abscissa. From this point draw a vertical broken line to cut the graph at a point. Enclose this point of intersection with a small circle. From this point of the graph, say A, draw a horizontal broken line to cut the ordinate. The value of the ordinate corresponding to this point of intersection gives the required value.

If the point of intersection A lies on the graph, the value of y is determined by the process of *interpolation*. If the point A lies on the extension one way or the other of the graph, the value of y is determined by the process of *extrapolation*.

Uses of Graph. Graphs are used for four main purposes :

(i) to deduce an average value of ratio,

(ii) to investigate how much individual values vary from the mean,

(iii) to show how one quantity varies with another, and

(iv) to deduce the mathematical relationships between two quantities.

Guide to the students. (1) Know beforehand the name of the experiment to be performed. Do not come to the laboratory without knowing the following basic points regarding the experiment :

(a) theory of the expt., (b) details of working of apparatus, and (c) the procedure with necessary precautions.

(2) While performing experiment, pay a special attention to the necessary precautions to be taken.

(3) Know beforehand the extent of the influence of the inaccuracies of particular measurements in the expt. on its final result.

(4) Measure carefully and precisely the quantity which contributes the maximum error in the result.

(5) The degree of accuracy in the measurement of any physical quantity also depends on the available apparatus. If it is not possible to have the measurement of a quantity with great precision, which has more influence on the result of the experiment, then it is advisable not to waste time in measuring the other quantities with great accuracy.

(6) Take large number of observations. Take readings in decimal instead of fraction.

(7) Record the readings in tabular form as far as practicable.

(8) Do not omit the 'zero' when a reading does happen to coincide with a scale division.

(9) Do not edit or manipulate a reading so as to make it come to the nearest scale division. The estimation of the last figure in a reading is vital for accuracy.

(10) Do not make it your aim that your readings shall agree with the readings of your friend, but get your own independent radings.

(11) Keep open and free mind without bias during experimental work. Neither assume that your first reading in a series of readings of the same quantity is correct, nor try to make later readings agree with it. Manipulated readings are valueless.

(12) Have trust on yourself only and if there is any difficulty ask your teacher.

(13) Keep the apparatus which is for the time being not in use near the middle of your working table.

(14) Do not place unwanted articles on your working table.

(15) Take care in handling the instruments and in transit of the instruments.

(16) Do not mix up plugs from the keys and resistance boxes.

(17) Any part of the apparatus requiring frequent use and adjustment should be placed within easy approach. Do not keep your body in awkward position while taking readings.

(18) Always throw water, acids, etc. in the sink.

(19) Avoid the metallic parts of the apparatus from the contact of acid, mercury, water and other chemicals.

(20) Do not jot down a few data on loose sheets of paper and trust the memory to fill in the gaps as it produces mistakes.

(21) Do not forget to write the units of every measurement made and of the final result.

(22) (i) Unless for some special reason it is desired to show a group of curves, a fresh piece of squared paper should be used for each graph.

(ii) Make sure you have labelled your axes with the quantities plotted along them and the units in which they are measured.

(iii) Do not forget to give the graph a title.

(iv) See that the deductions made from the graph appear either on it or very near it.

□□□

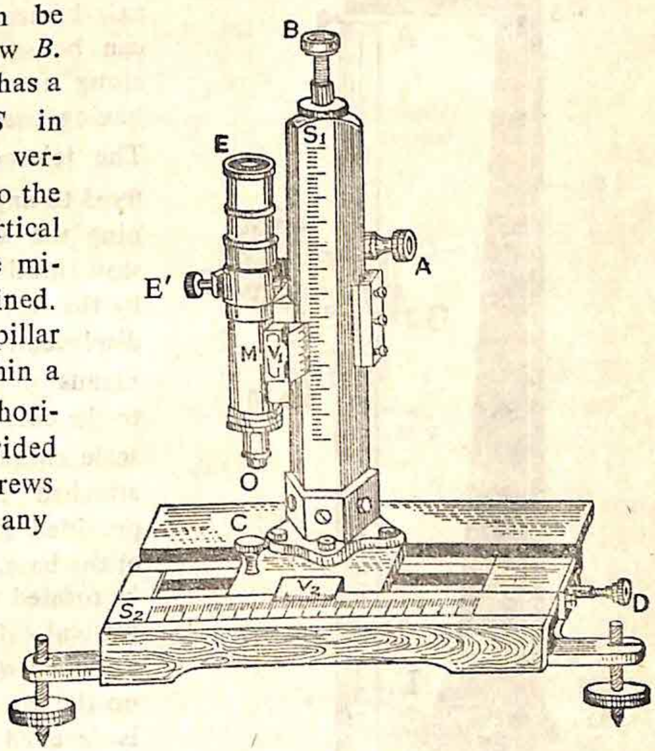
1. GENERAL PHYSICS

SOME COMMON INSTRUMENTS

1. Travelling Microscope

This instrument is used for measuring very small lengths. It consists of a compound microscope *M* which can slide up or down along a vertical pillar and can be fixed at any position by tightening the screw *A* and then a slow motion can be imparted by the screw *B*. The vertical pillar has a graduated scale *S* in centimetre. By the vernier V_1 attached to the microscope, the vertical displacement of the microscope can be obtained.

The vertical pillar itself can slide within a groove made on a horizontal base provided with three levelling screws and can be fixed at any position by tightening the screw *C* and then a slow motion can be imparted by the screw *D*. The horizontal displacement can be read by means of a vernier V_2 attached to the pillar, on a horizontal scale S_2 engraved on the base. The base should always be made horizontal; thereby the pillar becomes vertical.



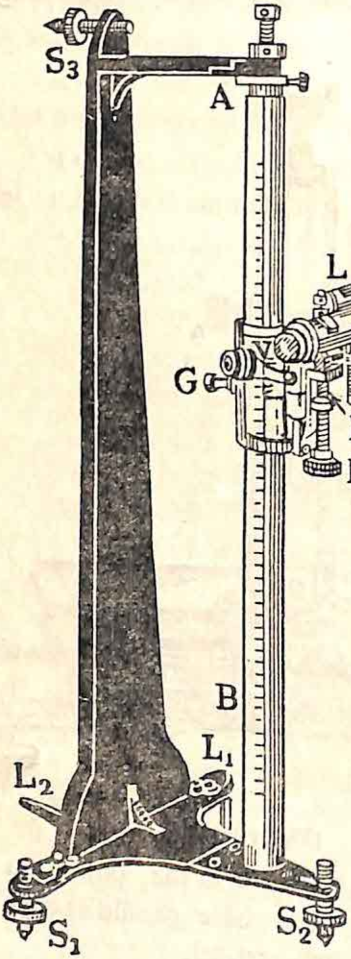
(Fig. 1.1)

The eye-piece *E* is fitted with cross-wires which should be sharply focussed by moving the eye-piece. By the screw *E'* attached to the microscpe, the whole microscope can be moved up or down, thus adjusting the distance of the objective *O* from the object and is used while focussing the microscope. There should not be parallax between the cross-wire and the image of object. The microscope can be kept horizontal, inclined or vertical.

In measuring the vertical length the axis of the microscope should be kept horizontal, while measuring the horizontal length, its axis should be kept vertical.

2. Cathetometer Telescope

It is an instrument used for measuring vertical distances (Fig. 1.2). It consists of a small telescope *T* fixed to a carriage with its axis horizontal. The carriage can be moved up and down along a vertical column *AB* having triangular cross-section. The telescope carriage can be fixed to any position by tightening the screw *G* and then a slow motion can be imparted by the screw *M*. The vertical displacement can be read by means of a vernier *V* attached to the carriage, on the vertical scale engraved on *AB* which is attached to a heavy frame provided with levelling screws at the base. The telescope can be rotated with *AB* about the vertical axis. The telescope is provided with a spirit level *L* on the top and the instrument is levelled with the help of levelling screws at the base and the screw *F* below the telescope in the telescope carriage. The instrument is also provided with a magnifying glass to facilitate the scale and vernier readings. The eye-piece of the telescope is fitted with cross-wires which should be sharply focussed by moving the eye-piece.



(Fig. 1.2)

In using the instrument care must be taken to ensure that (i) the vertical column AB is vertical, (ii) the axis of the telescope is horizontal, and (iii) the object is focussed on the cross-wires.

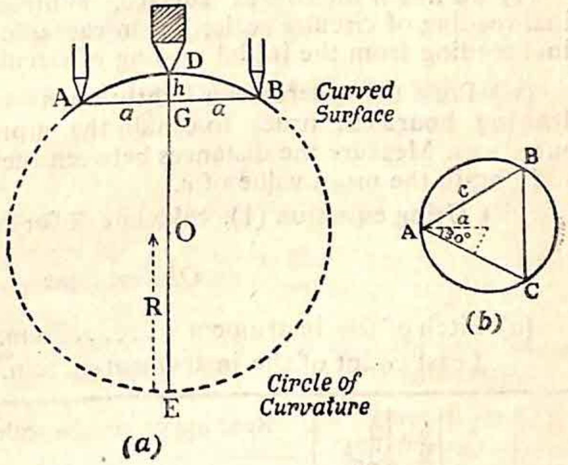
This instrument can also be used for measuring horizontal distances by keeping AB horizontal when the instrument stands on S_3 and L_2.

The use of a cathetometer involves serious errors and troublesome adjustments, and hence it is not very much used.

3. Spherometer

Determination of radii of curvatures of the convex and concave surfaces of a watchglass.

Theory. On placing the spherometer on a spherical surface, the three outer legs stand on the circumference of a circle of radius a (diameter AB). Let the height through which the centre leg is raised be h. Then if R is the radius of curvature of the spherical surface, we have from the properties of intersecting chords,
$AG \times GB = DG \times GE$,



(Fig. 1.3)

or $a^2 = h(2R-h)$, $\quad\therefore\quad R = \dfrac{a^2+h^2}{2h}$.

If c be the distance between the two outer legs of the spherometer,

$$\frac{c}{2} = a\cos 30^\circ, \qquad \therefore\quad a = \frac{c}{\sqrt{3}}.$$

Hence
$$R = \frac{c^2}{6h} + \frac{h}{2} \qquad \cdots \quad (1).$$

Procedure. (i) Find out the value of each division on the vertical scale. Next give 10 complete rotations to the disc by turning the milled head and find out by how many divisions of the vertical scale the disc advances. From this calculate the distance by which the screw head advances in one complete rotation. This gives the pitch of the instrument. Divide the pitch by the number of divisions on the circular scale. This gives the least count of the instrument, that is, the distance by which the screw head advances when the disc is turned through one division of the circular scale.

(ii) Place the spherometer on a plane glass plate and turn the milled head until the centre leg just touches the plate. Note down the initial reading of circular scale. Repeat it five times.

(iii) Next, place the spherometer on the convex surface of the watch glass. By turning the milled head, raise the centre leg until it just touches the convex surface. Note down the numbers of complete rotation and the final reading of the circular scale. Repeat it five times.

(iv) Similarly, find the number of complete rotations and the final reading of the circular scale for concave surface. Here the centre leg has to be lowered down.

(v) To find h for convex surface, subtract initial reading from final reading of circular scale; but in case of concave surface, subtract final reading from the initial reading of circular scale.

(vi) Press the spherometer lightly on a white paper fixed on a drawing board in order to obtain the impression of the tips of the outer legs. Measure the distances between these points with a scale and obtain the mean value of c.

(vii) Using equation (1), calculate R for both surfaces.

Observations

(*a*) Pitch of the instrument = ...cm.
Least count of the instrument = ..cm.

Surface used	No. of obs.	No. of Complete-rotn. (n)	No. of Complete-rotn. × Pitch $=A$ (cm.)	Readings on circular scale			Difference × L.C. $=B$ (cm)	Sum $=(A+B)$ $=h$ (cm)	Mean, h (cm)
				Initial T	Final F	Difference d			
Convex	1								
	2					$(F-I)$			
	.								
	.								
	5								
Concave	1								
	2					$(I-F)$			
	.								
	.								
	5								

(*b*) Distance between outer legs, (i)........cm; (ii)........cm; (iii)......cm. Mean, $c = ...$cm

Calculations. Radius of curvature of convex surface,

$R_1 = ...$cm

Radius of curvature of concave surface,

$R_2 = ...$cm

Result. $R_1 = ...$cm, and $R_2 = ...$cm.

Precaution. Avoid *back-lash error* by turning the screw always in the same direction while taking the different readings.

PHYSICAL BALANCE

EXPERIMENT 1. Determination of the mass of the given body by the method of oscillations applying buoyancy correction.

Apparatus. Balance, weight box, and the body to be weighed.

Theory. (*i*) *Method of Oscillations*—When the beam of a sensitive balance is released, the pointer continues to perform damped simple harmonic motion with decreasing amplitude. To wait for it to come to rest would make weighing a slow process and even the position of the true resting point would be affected by errors due to friction.

But it is not necessary to wait till the pointer comes to rest, for by noting the successive turning points of the pointer, *beginning from left* for two complete oscillations so that an *odd*[1] number of readings (five) are obtained, its positions of rest (resting point) can be determined in the following way. The mean of the *three* readings to the left as well as the mean of the *two* readings to the right are to be determined separately. The mean of these two means will give the resting point of the pointer. This method of weighing is called the *method of oscillations*.

Let P be the resting point of the pointer for an unloaded balance, Q be its resting point when the body is on the left pan and weights W_1 (slightly less than the mass of the body) on the right pan, and R for the load W_2 (slightly greater than the mass of the body).

Then since the shift of the resting point of the pointer for $(W_2 - W_1)$ gm is $(Q - R)$ divisions, the weight necessary to shift it through $(Q - P)$

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[1] The reason for an odd number of readings is, that due to the decreasing amplitude of oscillation due to friction at knife-edges, resistance of air etc., the resting point obtained from an even number of readings will be lying too much to one side of the correct resting point.

divisions will be $\frac{(Q-P)(W_2-W_1)}{(Q-R)}$. Hence the correct weight of the body,

$$W=\left[W_1+\frac{(Q-P)(W_2-W_1)}{(Q-R)}\right] \text{ gm.} \qquad \cdot\cdot \quad (1).$$

(ii) *Buoyancy Correction*—Since the body and weights counterpoising the body are in air, the upthurst of air is felt by both of them. Hence the weight so determined does not give the real weight of the body unless the volume of the body and that of the weights used are equal.

Let M be the true weight of the body (in vacuum); W, the weight of the weights counterpoising the body; D, the density of the body, d, the density of the weights and σ, the density of air. The volume of the body is $\frac{M}{D}$ and that of the weights is $\frac{W}{d}$. Hence the weight of the air displaced by the body is $\sigma\frac{M}{D}$ and that of the weights is $\sigma\,\frac{W}{d}$.

$$\therefore \quad M-\frac{\sigma M}{d}=W-\frac{\sigma W}{d}; \quad \text{or} \quad M=W\left(1-\frac{\sigma}{d}\right)\left(1-\frac{\sigma}{D}\right)^{-1};$$

$$\text{or} \quad M=W\left(1-\frac{\sigma}{d}\right)\left(1+\frac{\sigma}{D}\right)=W\left(1-\frac{\sigma}{d}+\frac{\sigma}{D}\right),$$

neglecting higher powers of σ/D and σ^2/Dd

$$=W\left\{1+\sigma\left(\frac{1}{D}-\frac{1}{d}\right)\right\} \qquad \cdot\cdot \quad (2).$$

Usually W consists of weights of brass (W' gm.) and aluminium (W'' gm). Hence relation (2) may be written as

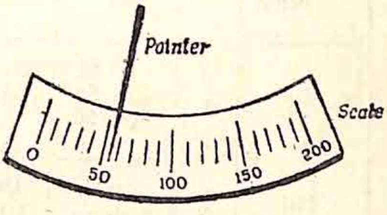
$$M=W'\left\{1+\sigma\left(\frac{1}{D}-\frac{1}{d_B}\right)\right\}+W''\left\{1+\sigma\left(\frac{1}{D}-\frac{1}{d_A}\right)\right\} \qquad \cdot\cdot \quad (3).$$

where d_B and d_A are densities of brass and aluminium respectively. Putting the value of σ, d_B and d_A, we have

$$M=W'\left\{1+0\cdot0012\left(\frac{1}{D}-\frac{1}{8\cdot40}\right)\right\}+W''\left\{1+0\cdot0012\left(\frac{1}{D}-\frac{1}{2\cdot70}\right)\right\} \cdot\cdot \ (4).$$

Procedure. (i) Clean the balance by a camel-hair brush or by a clean cloth and see that all parts are in their proper places. Adjust the levelling screws until the plumb line is vertical. Raise the beam from the arrestors by turning the handle (or the knob) and see that the pointer oscillates freely. Adjust the screw nuts at the ends of the beam until the pointer swings *almost equally* on both sides of the central mark of the ivory scale. Remember that the adjustments should be done only when the beam is arrested. Also the handle should be turned to arrest the beam only when the pointer is passing through the central mark.

(ii) To make calculation easy, assume the central mark of the scale to be 100, the marks to thel eft as 90, 80....and to the right as 110, 120,.. as shown in Fig. 1.4. Raise the beam carefully and set it swinging by careful manipulation of the arresting control (or by fanning one pan with the hand) so that the pointer swings freely over the scale not exceeding three-fourth of the entire scale. When the turning points are, say, little less than 50 on the left side, *close* the *glass door* of the balance case. After a few oscillations the pointer will swing *steadily*.



(Fig. 1.4)

(iii) Take readings of the turning points of the pointer for two successive oscillations, three to the left and two to the right. Readings between the marks should be taken by eye-estimation (each estimated division should be 1), avoiding parallax. Take the mean of the three readings to the left and that of the two readings to the right. Find the mean of the two means which will give resting point of the unloaded balance.

(iv) Repeat the above process (iii) three times, raising the beam every time and taking the readings of five consecutive turning points beginning from left. Find the mean of these three resting points. Call it P. This should be near the central mark of the scale.

(v) Now place the body to be weighed on the left pan and suitable weights on the right pan. To begin with use a higher weight and then systematically reduce it until the pointer swings about a mean position which is 4 or 5 divisions right than that in the unloaded condition. Obtain as before the mean resting point (Q) of the loaded balance. Rider may be used for finer adjustments. Record the weights lying on the pan and call it W_1.

(vi) Next obtain the mean resting point (R) with the addition of 4 or 5 mgm (or nearly 10 mgm if the balance is not sufficiently sensitive) on the right pan. Record the weights again and call it W_2. R should be a little less than P.

(vii) Calculate the weight of the body from the relation (1).

(viii) Note down the density of the body which is weighed, from a book of constants. Calculate the true weight of the body using the relation (4).

Observations

Density of the body (lead), $D = 11{\cdot}37$ gm/cc.

Load on Pans		No. of obs.	Turning Points		Mean		Resting Point	Mean Resting Point
Left	Right		Left	Right	Left	Right		
Nil	Nil	1	(i) 51 (iii) 54 (v) 56	(ii) 150 (vi) 147	53·7	148·5	101·1	
		2	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...	...	...	
		3	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...	...	...	(=*P*)
Body	20·0 10·0 0·0 0·05 30·25 gm (=W_1 gm)	1	(i) 60 (iii) 63 (v) 65	(ii) 151 (iv) 149	62·7	150	106·3	
		2	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...	...	...	
		3	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...		...	(=*Q*)
Body	20·0 10·0 0·2 0·05 0·01 30·26 gm (=W_2 gm)	1	(i) 55 (iii) 58 (v) 60	(ii) 138 (iv) 135	57.7	136·5	97·1	
		2	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...	...	...	
		3	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...	...	...	(=*R*)

Calculations. Weight of the body

$$W = \left[W_1 + \frac{(Q-P)(W_2 - W_1)}{Q-R} \right] \text{ gm}$$

$$=\left[30{\cdot}25+\frac{5{\cdot}2+0{\cdot}01}{9{\cdot}2}\right]\text{ gm}$$

$$=(30{\cdot}25+{\cdot}005)=30{\cdot}255\text{ gm.}$$

$\therefore$ True weight of the body

$$M=W'\left\{1+0{\cdot}0012\left(\frac{1}{D}-\frac{1}{8{\cdot}40}\right)\right\}+W''\left\{1+0{\cdot}0012\left(\frac{1}{D}-\frac{1}{2{\cdot}70}\right)\right\}$$

$$=30\left\{1+0{\cdot}0012\left(\frac{1}{11{\cdot}37}-\frac{1}{8{\cdot}40}\right)\right\}$$

$$\times 0{\cdot}255\left\{1+0{\cdot}0012\left(\frac{1}{11{\cdot}37}-\frac{1}{2{\cdot}70}\right)\right\}$$

$$=29{\cdot}999+0{\cdot}255=30{\cdot}254\text{ gm.}$$

Result. Wt. of the body $=30{\cdot}255$ gm.

True wt. of the body $=30{\cdot}254$ gm.

Precautions. (i) The body to be weighed must not exceed the maximum weight permissible for that balance. (ii) While adding or removing weights, the beam should be arrested first and then weights should be added or removed. (iii) At the time of recording, the left turning points should lie approx. between 40 and 80, and the right turning points between 120 and 160. (iv) P should lie between Q and R. (v) The glass door of the balance case should be closed while taking readings of the turning points.

EXPERIMENT 2. **Determination of sensitivity of a balance with different loads.**

Apparatus. Balance, and two weight boxes.

Theory. The sensitivity of a balance is the number of scale divisions through which the pointer moves due to 1 mgm difference of weight in the pans. The angular deflection θ of a balance beam due to an excess weight w mgm is given by

$$\tan\theta=\frac{wa}{1000\,W\,h},$$

where a is the length of the arm; W, the weight of the beam in gm and h, the distance between the centre of gravity of the beam and the fulcrum. As θ is small, $\tan\theta=\theta=\dfrac{d}{l}$, where d is the displacement of the pointer on the scale and l, the length of the pointer. Hence

$$\text{Sensitivity}=\frac{d}{w}=\frac{al}{1000\,Wh}.$$

This shows that the sensitivity is higher (i) the longer the arm, (ii) the smaller the value of h, (iii) the lighter the beam, and (iv) the longer the pointer.

When the three knife-edges are parallel and lie in the same plane the sensitivity is maximum and does not change with load. Usually the central knife-edge remains a little below the plane of the terminal knife-edges and hence sensitivity is *less* than the maximum value. When equal weights are placed on the pans, the beam bends and lowers the terminal knife-edges. Consequently, the sensitivity increases. When the weights added on the pans are sufficient to lower the terminal knife-edges below the central one, the sensitivity decreases again. Hence the sensitivity at first increases with load, then remains constant, and finally decreases.

Procedure. (i) Make all the preliminary adjustments of the balance.

(ii) Determine the resting point P of unloaded balance by noting five consecutive turning points, beginning from left.

(iii) Again determine the resting point Q when an extra weight of 2* mgm (say) is added on the right pan (by putting rider on the second mark of the right arm). Now calculate the sensitivity of the balance for *no load* from the relation given below :

$$\text{Sensitivity}=\frac{P-Q}{2}\ \text{div./mgm.}$$

(iv) Place 10 gm weight on each pan.† Determine the resting point. Add 2 mgm. to the right pan and again determine the resting point. Calculate the sensitivity for a load of 10 gm.

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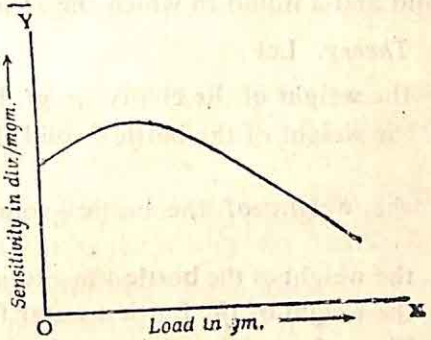
* If the balance is not so sensitive, add 4 or 5 mgm instead of 2 mgm.

† If two weights are not exactly equal, place a rider on a suitable mark on the beam so that the pointer oscillates nearly equal divisions on both the sides of the central mark of the scale. The weight so added by rider should not be taken into account as that has been added simply to equalise the two 10 gm weight.

(v) Repeat the operation (iv) with 20, 30, 40, etc. gm weight on each pan. In this way finish the experiment when the balance has been loaded up to the maximum permissible load for that balance.

(vi) Plot a graph with load along *x*-axis and the corresponding sensitivity along *y*-axis. The nature of the graph will be of the type shown in fig. 1.5. This graph shows the variation of sensitivity with loads.



(Fig. 1.5)

Observations

No. of obs.	Load on Pans		Turning Points		Mean		Resting Point	Sensitivity $=\frac{P-Q}{2}$ div./mgm
	Left	Right	Left	Right	Left	Right		
1	0	0	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...	...	... (=*P*)	...
	0	2 mgm	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...	...	... (=*Q*)	
2	10 gm	10 gm	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...	...	... (=*P*)	...
	10 gm	10 gm + 2 mgm	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...	...	... (=*Q*)	
3								
4								
...								
...								

Conclusion. The sensitivity at first increases with load, then remains constant and finally decreases.

Note. Here it is sufficient to determine the resting point once only at each load.

EXPERIMENT. 3. Determination of the spacific gravity of a solid* soluble in water using a specific gravity bottle.

Apparatus. Sp. gr. bottle†, balance, weight-box, thermometer, solid and a liquid in which the solid does not dissolve.

Theory. Let

the weight of the empty sp. gr. bottle $= W_1$ gm,
the weight of the bottle+solid (filling about half of the bottle) $= W_2$ gm,
the weight of the bottle+solid+insolvent liquid (filling rest of the bottle) $= W_3$ gm,
the weight of the bottle+insolvent liquid filling the bottle $= W_4$ gm,
the weight of the bottle+water filling the bottle $= W_5$ gm.
Then, the weight of the solid taken $= (W_2 - W_1)$ gm,
the weight of an equal volume of the insolvent liquid $= [(W_4 - W_1) - (W_3 - W_2)]$ gm,
the weight of the insolvent liquid filling the bottle $= (W_4 - W_1)$ gm,
the weight of water filling the bottle $= (W_5 - W_1)$ gm.
∴ Sp. gr. of solid with respect to insolvent liquid

$$S_1 = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)},$$

and sp. gr. of insolvent liquid with respect to water at room-temperature

$$S_2 = \frac{W_4 - W_1}{W_5 - W_1}.$$

∴ Sp. gr. of solid, $S = S_1 \times S_2 \times \rho_t$ [∵ ρ_t, the density of water at t°C, is numerically equal to its sp. gr. in c.g.s. system]

$$= \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \times \frac{W_4 - W_1}{W_5 - W_1} \times \rho_t.$$

Procedure. (i) Wash the bottle with dilute caustic soda, then with dilute nitric acid and finally with water for several times. Fill the bottle carefully with water (preferably distilled water and carefully insert the stopper so that no air-bubble is left within. Wipe off the excess water on the outer sides of the bottle by means of a clean blotting or filter paper. Determine its weight (W_5) by the *method of oscillations*.

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* Applying temperature correction.

† It is a bottle with narrow neck so that error due to surface tension effect in filling it with liquid is as small as possible. It is provided with a ground glass stopper having a capillary bore.

(ii) Then throw away the water and dry the bottle and the stopper by passing hot air and determine the weight of the empty bottle with the stopper (W_1) by the method of oscillations.

(iii) Fill the bottle about a half with the given solid (say, salt). Determine its weight with the stopper (W_2) by the method of oscillations.

(iv) Fill the rest of the bottle with insolvent liquid (usually, kerosine oil) taking care that no air bubble is left sticking to the solid within the bottle. Shaking the bottle may be of help. Carefully inserts the stopper and wipe off the excess liquid on the outer sides of the bottle as before. Determine its weight (W_3) by the method of oscillations.

(v) Now throw away the liquid and solid and wash the bottle several times with the liquid so that last traces of solid are removed. Fill the bottle completely with the liquid. Carefully insert the stopper and wipe off the excess liquid on the outer sides of the bottle. Determine its weight (W_4) by the method of oscillations.

(vi) Note the temperature of the water by a thermometer. Note down the density of water (ρ_t) in c.g.s. system at that temperature from a book of constants.

Observations

Temperatures of water, $t = \ldots.$ °C.

Density of water at $(t)\ldots.$ °C, $\rho_t = \ldots\ldots.$ gm/cc.

Load on Pans		Turning Points		Mean		Resting Point
Left	Right	Left	Right	Left	Right	
Nil	Nil	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...	...	...
Bottle+ Water (W_5)	... gm	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...	...	...
,,	...gm + ...mgm	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...	...	...

$W_5 = \ldots.$ gm.

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Loan on Pans		Turning Points		Mean		Resting Point
Left	Right	Left	Right	Left	Right	
Empty bottle (W_1)	...gm	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...	...	...
	...gm + ...mgm	(i) ... (iii) ... (v) ...	(ii) ... (iv) ...	...	...	...

$$\therefore \quad W_1 = \ldots\ldots \text{gm}.$$

Similarly tabulate data for the other weights.

Calculations. Sp. gr. of solid

$$S = \frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)} \times \frac{W_4 - W_1}{W_5 - W_1} \times \rho_t.$$

Result. Sp. gr. of solid = ...

Precautions. (i) Air bubbles should not stick to the bottle or the solid within the bottle. (ii) The outer sides of the bottle should be dry before each weighing. (iii) Hold the bottle as little as possible so as to minimise the loss of liquid due to expansion caused by the heat of the hand. Hold the bottle by its neck.

Note. If the solid is *insoluble* in water, water should be used in place of liquid. Hence, $S = \dfrac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \times \rho_t$,

where W_3 = wt. of bottle + solid + water filling the rest of the bottle,
and W_4 = wt. of bottle + water filling the bottle.

ASSOCIATED EXPERIMENTS

1. *Find the lengths of the two wires in the given tangle without untangling it. Samples of wires are supplied.*

Hint. Determine the weights of the tangle in air and water. Find the loss in weight (in gm.) which will give the volume of the tangle, V (in cc). Calculate its density D (in gm/cc). Again determine the densities d_1 and d_2 of the samples. Measure the radii of the wires r_1 and r_2 by means of a screw gauge.

Let M = mass of the tangle,

m_1 = mass of the first wire, m_2 = mass of the second wire,

v_1 = volume of the first wire, v_2 = volume of the second wire,
l_1 = length of the first wire, l_2 = length of the second wire.

Then,

$$V = v_1 + v_2, \quad \text{or} \quad \frac{M}{D} = \frac{m_1}{d_1} + \frac{m_2}{d_2} \quad .. \quad (1).$$

Also
$$M = m_1 + m_2, \quad \text{or} \quad \frac{M}{d_2} = \frac{m_1}{d_2} + \frac{m_2}{d_2} \quad .. \quad (2).$$

Subtracting (2) from (1), we get

$$m_1\left(\frac{1}{d_1} - \frac{1}{d_2}\right) = M\left(\frac{1}{D} - \frac{1}{d_2}\right)$$

or
$$\frac{m_1}{d_1}\left(\frac{d_2 - d_1}{d_2}\right) = \frac{M}{D}\left(\frac{d_2 - D}{d_2}\right)$$

or
$$v_1\left(\frac{d_2 - d_1}{d_2}\right) = V\left(\frac{d_2 - D}{d_2}\right);$$

$$\therefore \quad v_1 = V\left(\frac{d_2 - D}{d_2 - d_1}\right) \quad .. \quad (3).$$

Again,
$$v_2 = V - v_1 = V\left(\frac{D - d_1}{d_2 - d_1}\right) \quad .. \quad (4).$$

Now, $\pi r_1^2 l_1 = v_1$; $\therefore$
$$l_1 = \frac{v_1}{\pi r_1^2} = \frac{V(d_2 - D)}{\pi r_1^2(d_2 - d_1)} \quad .. \quad (5).$$

Similarly,
$$l_2 = \frac{V_2}{\pi r_2^2} = \frac{V(D - d_1)}{\pi r_2^2(d_2 - d_1)} \quad .. \quad (6).$$

From equations (5) and (6), calculate l_1 and l_2.

Note. All weighings should be done by the method of oscillations.

2. *Find the number of steel balls hidden in a given lump of paraffin. Samples of paraffin and steel balls are given.*

Hint. Determine the density D and volume V of the lump. Determine the density d_1 of the paraffin (sample). Measure the radius r of the steel ball (sample) by means of a screw gauge and also determine its weight m. Calculate the density d_2 of the steel ball. It is advisable to find the average mass and radius of the ball by taking 5 balls.

Let n = no. of steel balls hidden in the lump,
$v = \frac{4}{3}\pi r^3$ = volume of one steel ball.

$\therefore$ density of the steel ball, $d_2 = \frac{m}{v}$,

and the volume of steel balls hidden, $v_2 = nv$.

Now $V = v_1 + v_2$, or $v_1 + nv = V$

or $n = \frac{V - v_1}{v}$, where $v_1 = V\left(\frac{d_2 - D}{d_2 - d_1}\right)$ [from Q. 1].

Knowing v_1, V and v, find n. Note that all weighings should be done by the method of oscillations.

3. *Find the volume of air enclosed in the given glass bulb. A sample of glass is given.*

Hint. Determine the wt. of the bulb (W_1) in air, wt. of the sinker (W_2) in water and the wt. of the sinker and bulb, (W_3), both in water. Find the volume of the bulb, $V\left[= \frac{W_1 - (W_3 - W_2)}{\rho_t}\right]$.

Determine the density d of the glass (sample).

Now, valume of the bulb = volume of air inside + volume of the glass envelope.

But volume of the glass envelope $= \frac{W_1}{d}$ (neglecting the mass of the air inside).

$$\therefore \text{ Volume of air inside} = \left(V - \frac{W_1}{d}\right) \text{ (in cc).}$$

Note. All weighings should be done by the method of oscillations.

4. *Find the volume of air enclosed in the given piece of cork.*

Hint. If W_1 = wt. of the cork in air,

W_2 = wt. of the sinker in water,

W_3 = wt. of the sinker and cork, both in water (when cork is *not boiled*),

W_4 = wt. of the sinker and cork, both in water (when cork is *boiled* for about 15 minutes);

$\therefore$ Volume of cork + air inside $= \frac{W_1 - (W_3 - W_2)}{\rho_t}$,

and volume of cork alone $= \frac{W_1 - (W_4 - W_2)}{\rho_t}$, where ρ_t is the density (gm/cc) of water at t°C.

$$\therefore \text{ Volume of air inside} = \frac{W_1=(W_3-W_2)}{\rho_t} - \frac{W_1-(W_4-W_2).}{\rho_t}$$

All weighings should be done by method of oscillations.

5. *A mixture of sugar and salt is given. Find its percentage composition. Samples are supplied.*

Hint. Using sp. gr. bottle, determine the mass M and density D of the mixture. Also determine the density d_1 of salt and density d_2 of sugar [using the samples supplied].

$$\therefore \text{ Volume of the mixture, } V=\frac{M}{D}.$$

Also, volume of the salt in the mixture, $v_1 = V\left(\frac{d_2-D}{d_2-d_1}\right)$ and the volume of the sugar in the mixture, $v_2=V\left(\frac{D-d_1}{d_2-d_1}\right)$. [See Q.1]

Using the above relations, find V, v_1 and v_2.

Hence percentage of salt $=\frac{v_1}{V}\times 100$,

and the percentage of sugar $=\frac{v_2}{V}\times 100$.

Also for percentage by mass,

p. c. of salt $=\frac{v_1 d_1}{VD}\times 100$ and p.c. of sugar $=\frac{v_2 d_2}{VD}\times 100$.

6. *Show how the density varies with concentration of a solution of common salt.*

Hint. Take 200 cc of water in a measuring cylinder and dissolve in it about 10 gm of salt (previously weighed in a watch glass). Using sp. gr. bottle find the density of this solution. Repeat this process dissolving 20, 30, 40, etc. gm of salt in 200 cc of water. Plot a graph taking concentration (mass of the salt dissolved per 100 gm of water) along the x-axis and density on the y-axis. The resulting graph will be a straight line.

7. *Find the specific gravity of sodium chloride at* 45°C.

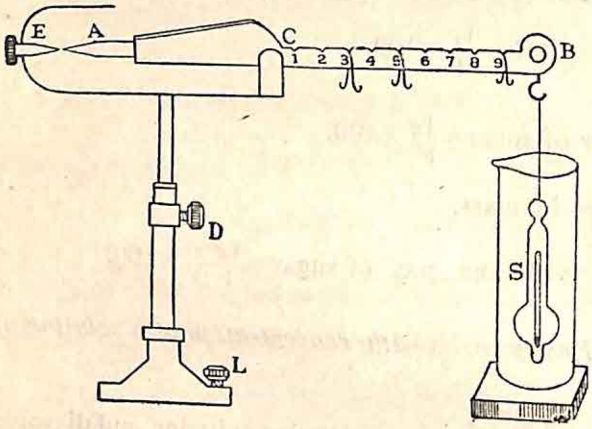
Hint. Find the weights W_1 and W_2 as described in Expt. 3. But, before finding W_3, W_4 or W_5, bring the liquid or water taken in the bottle at constant temperature of 45°C. For this, suspend the bottle inside a beaker containing water. Heat the beaker and stir the water constantly. When the temperature of the water in the beaker approaches 45°C (indicated by a thermometer suspended in the beaker), remove the burner for a moment and again bring it below the beaker till the temperature is constant at 45°C. After a few minutes, take out the bottle. Cool it and weigh it. Here ρ_t is the density of water at 45°C.

MOHR'S BALANCE

EXPERIMENT 4. Determination of the density of a liquid by Mohr's balance.

Apparatus. Mohr's balance, glass cylinder, liquid (copper sulphate solution, kerosene oil, etc.) and distilled water.

Description of the apparatus : MOHR'S BALANCE. It consists of a beam *AB* pivoted at *C* on a knife-edge. A sinker *S* (usually provided with a thermometer inside it) hangs freely from *B* by fine metal wire. The weight of the sinker and of a counterpoise on the arm *CA* are so adjusted that when *S* hangs freely in air, the pointed end *A* lies in line with the pin *E*. To ensure this, there is a levelling screw *L*. The arm *CB* is divided into *ten* equal parts. The pivot supporting the beam is mounted on a stand whose height can be adjusted by the screw *D*.



(Fig. 1.6)

It is also provided with three types of riders, large, medium and small, whose weights are in the ratio 1 : 0·1 : 0·01. Usually, there are two riders of each type.

Theory. When the sinker is immersed in water of density ρ_t at temperature t°C, suppose the equilibrium is restored (i.e., the pointed end A is brought in a line to pin E) by placing *large* rider of weight w on the xth mark of the graduted arm of length l, the *medium* rider of weight $\frac{w}{10}$ on the yth mark, and the *small* rider of weight $\frac{w}{100}$ on the zth mark. Then,

$$v\rho_t.l = w.\frac{x}{10}\cdot l + \frac{w}{10}\cdot\frac{y}{10}\cdot l + \frac{w}{100}\cdot\frac{z}{10}\cdot l,$$

or

$$v\rho_t = \left(\frac{x}{10} + \frac{y}{100} + \frac{z}{1000}\right)w \quad \cdot\cdot \quad (1),$$

where v is the volume of the sinker.

When the sinker is immersed in a liquid of density ρ, suppose the equilibrium is restored by placing large rider on the mth mark, the medium rider on the nth mark and the small rider on the pth mark. Then

$$v.\rho l = w.\frac{m}{10}\cdot l + \frac{w}{10}\cdot\frac{n}{10}\cdot l + \frac{w}{100}\cdot\frac{p}{10}\cdot l$$

or

$$v\rho = \left(\frac{m}{10} + \frac{n}{100} + \frac{p}{1000}\right)w \quad \cdot\cdot \quad (2)$$

Dividing (2) by (1), we get

$$\frac{\rho}{\rho_t} = \frac{\left(\frac{m}{10} + \frac{n}{100} + \frac{p}{1000}\right)}{\left(\frac{x}{10} + \frac{y}{100} + \frac{z}{1000}\right)};$$

$$\therefore \ \rho = \left(\frac{m}{10} + \frac{n}{100} + \frac{p}{1000}\right)\cdot\frac{\rho_t}{\left(\frac{x}{10} + \frac{y}{100} + \frac{z}{1000}\right)} \quad \cdot\cdot \quad (3).$$

The first term on the right-hand side is called the *apparent density* and the second term, the *correction factor* being equal to density of water at t°C divided by $\left(\frac{x}{10} + \frac{y}{100} + \frac{z}{1000}\right)$ in the above case (that is, the apparent density of water).

Procedure. (i) By means of screw D adjust the height of the beam until the sinker is well inside the glass cylinder (of course, empty) placed on a table.

(ii) See that A is in line with E, when the sinker is hanging *freely* in air. If not, bring it by means of screw L and if necessary, rotate the base without disturbing the upper part of the instrument. L should be in the vertical plane passing through the axis of the beam.

(iii) Fill the glass cylinder with distilled water and place it so that the sinker is completely immersed in it, without touching the walls of the cylinder. The equilibrium will be disturbed. Bring back the equilibrium by placing riders over the marks on the arm CB. Note the graduations on which the riders have been placed and the types of them. Repeat it three times. This will give the apparent density of water.

(iv) Note the temperature of water by the thermometer. Note down the density of water (ρ_t) at the temperature from a book of constants. Calculate the correction factor.

(v) Wipe of the water on the outer sides of the sinker by means of a blotting or filter paper. Take the liquid (copper sulphate solution, kerosene oil, etc.) in the cylinder in place of water and place it so that the sinker is completely immersed in it without touching the walls of the cylinder. Bring back the equilibrium by placing rider over the marks on the arm CB. Note the graduations on which the riders have been placed and the types of them. Repeat it three times. This will give the apparent density of the liquid taken. Multiply the apparent density of the liquid with the correction factor which will give the real density of the liquid. Also note down the temperature of the liquid.

(vi) Repeat the operation (v) with another liquid.

Observations and Calculations

Enter your data as shown below :

Temperature of water, $t=25°\text{C}$.

Density of water at 25°C, $\rho_t=0{\cdot}997$ gm/cc (from the book of Constants).

(A) *Readings for the apparent density of water.*

No. of obs.	Position of riders			Apparent density of water (gm/cc)	Mean (gm/cc)
	Large	Medium	Small		
1	9	4	9	0·949	
2	9	5	0	0·950	0·948
3	9	4	6	0·946	

$$\therefore \text{ Correction factor} = \frac{\rho_t}{\text{App. density of water}} = \frac{0{\cdot}997}{0{\cdot}948} = 1{\cdot}051.$$

(B) *Readings for the density of liquid.*

Liquid used	No. of obs.	Position of riders			Apparent density (gm/cc)	Mean App. density (gm/cc)	Correction factor	Real density (gm/cc)	Temperature (°C)
		Large	Medium	Small					
Copper sulphate solution	1	9+3	2	0	1·22	1·22 (say)	1·051	1·282	25°C
	2	...	...	...	...				
	3	...	...	...	...				
Kerosene oil	1	7	5	6	0·756	0·756 (say)	1·051	0·794	25°C
	2	...	...	...	...				
	3	...	...	...	...				

Result. Density of copper sulphate solution at 25°C = 1·282 gm/cc
" " kerosene oil at 25°C = 0·794 gm/cc.

Precaution. (i) Air bubbles should not stick to the outer side of the sinker. (ii) At the time of bringing *A* in line with *E* the nstrument should be protected from air draughts.

ASSOCIATED EXPERIMENT

1. *Check the graduations of a common hydrometer by a Mohr's balance.*

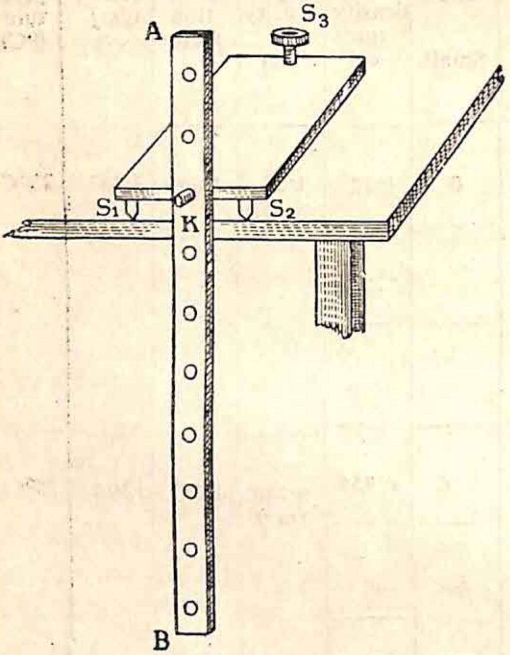
Hint. Using different liquids, determine the density of each liquid by both the instruments. Plot a graph taking density ρ (as measured by Mohr's balance) along the x-axis and correction, $(\rho - \rho')$ (ρ' is the density measured by hydrometer) along the y-axis.

ACCELERATION DUE TO GRAVITY

EXPERIMENT 5. Determination of 'g' by a bar-pendulum.

Apparatus. The bar-pendulum, knife-edge attached to a rigid support, metre scale, stop-clock and spirit level.

Description of the apparatus. BAR PENDULUM.* It consists of a metal bar about a metre long and about 2 cm wide, drilled with small holes (nearly 5 mm in diameter) at regular intervals (about 2 cm apart) supported by a knife-edge through these holes. The knife-edge † is fixed in a wooden board in front of which there are two screws, while at its back there is an adjustable levelling screw.



(Fig. 1.7)

Theory. The periodic time of a compound pendulum is given by

$$T = 2\pi\sqrt{\frac{k^2 + h^2}{hg}} \quad .. \quad (1),$$

where T is the periodic

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*If this is not available a metre rule can be used with small holes drilled symmetrically at intervals of 4 cm. A knitting needle passes through these holes and supports the rule on two rigidly held razor blade edges.

† There can be slight variations in the manner of suspending the pendulum with the knife-edge.

time in sec, h the distance of the knife-edge support (point of suspension) from the centre of gravity of the bar (pendulum), in cm, k the radius of gyration about an axis through c.g. and parallel to the axis of rotation, in cm, and g the acceleration due to gravity in cm/sec/sec.

Rewriting eqn. (1) as a quadratic in h, we have

$$h^2 \frac{T^2g}{4\pi^2} h+k^2=0 \qquad .. \quad (2).$$

Eqn. (2) will have two values of h, say h_1 and h_2. Hence

$$h_1+h_2=\frac{T^2g}{4\pi^2}, \qquad \text{or} \qquad g=4\pi^2.\frac{h_1+h_2{}^*}{T^2} \qquad .. \quad (3),$$

$$\text{and} \quad h_1h_2=k^2, \qquad \text{or} \qquad k=\sqrt{h_1h_2} \qquad .. \quad (4).$$

Since the sum and produces of h_1 and h_2 are positive, so h_1 and h_2 are both positive. Hence there are two points of suspension on the same side of c.g. for which the periods (T) would be the same. Similarly on the other side of c.g. there will be two points of suspension for which the periods would again be equal to T. The distance between two such points which are asymmetrically situated with respect to c.g. and for which the period of oscillation is T, will be length of the equivalent simple pendulum [from fig. 1.8, $PR=QS=$ length of the equivalent simple pendulum].

From eqn. (1) it is obvious that T will be minimum when the expression $\frac{k^2+h^2}{h}$ is minimum.

Now $\frac{k^2+h^2}{h}=\frac{(k-h)^2+2kh}{h}=\frac{(k-h)^2}{h}+2k$. This is minimum when $k=h$. Thus the minimum time period,

$$T_0=2\pi\sqrt{\frac{k^2+k^2}{kg}}=2\pi\sqrt{\frac{2k}{g}} \qquad .. \quad (5).$$

By determining T and finding other required quantities from the graph, g can be found out.

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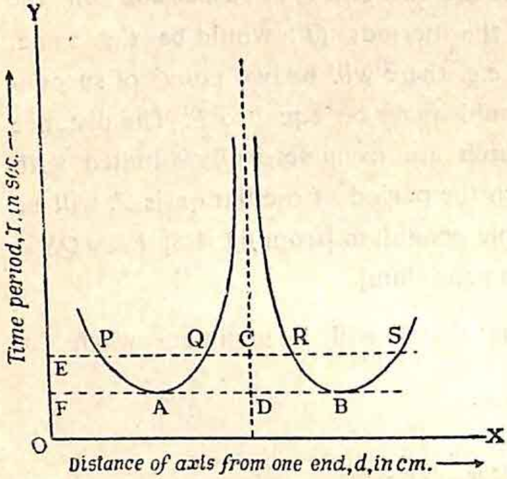
* So (h_1+h_2) gives the length of the equivalent simple pendulum.

Procedure. (i) Make the knife-edge horizontal by the levelling screw S_3 testing the adjustment with a spirit-level.

(ii) Suspend the bar on the knife-edge by introducing it in one hole nearest to one end (say, A). Oscillate the pendulum with a *small* amplitude. Its plane of vibration should be vertical. Note down the time[*] for 50 oscillations by means of an *accurate* stop-clock and repeat it three times. Dividing the mean by 50, find out the time period T. Measure the distance d of the knife-edge from the end A by a scale.

(iii) In this way determine the time period T[†] and distance d when it is *successively* suspended from the holes.

(iv) Plot a graph taking the time-period T along the y-axis and the distance d of the knife-edge from the end A along the x-axis. The graph will be as shown in fig. 1.8 and will consist of two symmetrical branches. Join A and B and bisect AB at D. Then the x-coordinate of D will give the position of c.g. of the bar. Draw a horizontal line parallel to the x-axis cutting the curves in four points, P, Q, R and S. Measure PC and CS (the mean of which gives h_1), QC and CR (the mean of which gives h_2) and OE (which gives the correspondnig time-period T).



(Fig. 1.8)

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[*] To facilitate the counting of oscillations correctly, use a telescope. For this purpose make a mark (or attach a pin) on the end of B of the rod and focus the telescope on it such that there is no parallax between its image and the vertical cross-wire of the telescope.

[†] Near the centre of the bar the period is large and so smaller number of oscillations may be taken.

Measure* also AB (which gives $2k$) and OF (which gives T_0). Calculate the value of g and k from the equation given above.

Observations

Hole No.	Distance of knife-edge from one end (say A) of the bar, in cm (d)	No. of oscillations	Time taken				Time-period in sec (T)
			I	II	III	Mean	
1							
2							
3							
.							
.							
.							

Calculations. From graph

(1)
$$\left.\begin{array}{l}\left.\begin{array}{l}PC=\ldots.\text{cm}\\ CS=\ldots.\text{cm}\end{array}\right\}\text{ Mean } h_1=\ldots.\text{cm}\\ \left.\begin{array}{l}QC=\ldots.\text{cm}\\ CR=\ldots.\text{cm}\end{array}\right\}\text{ Mean } h_2=\ldots.\text{cm}\end{array}\right\}\quad\therefore\ h_1+h_2=\ldots.\text{cm.}$$

$$T=OE=\ldots.\text{sec,}\qquad\therefore\ T^2=\ldots.\text{sec}^2.$$

$$\therefore\qquad g=4\pi^2.\ \frac{h_1+h_2}{T^2}=\ldots.\text{cm/sec/sec.}$$

Also, $2k=AB=\ldots.\text{cm},\ T_0=OF=\ldots.\text{sec.}$

$$\therefore\qquad g=4\pi^2\frac{2k}{T_0{}^9}=\ldots\ldots\text{cm/sec/sec.}$$

(2)
$$k=\frac{AB}{2}=\ldots\ldots\text{cm}$$

$$k=\sqrt{h_1h_2}=\ldots\ldots\text{cm.}$$

Value of k calculated from the dimension of the bar

$$=\frac{\text{length of the bar}}{\sqrt{12}}=\ldots\ldots\text{cm.}$$

(3) The position of the c.g. of the bar from the end A

$$=FD=\ldots\ldots\text{cm.}$$

Result—(1) The value of $g=\ldots\ldots$cm./sec./sec.

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* Usually it is difficult to locate the exact positions of minima points on the graph. So do not use such measurements to determine g and k.

(2) The radius of gyration about an axis through c.g. and parallel o the axis of rotation (perpendicular to its length),

$$k = \ldots\ldots\ldots \text{cm.}$$

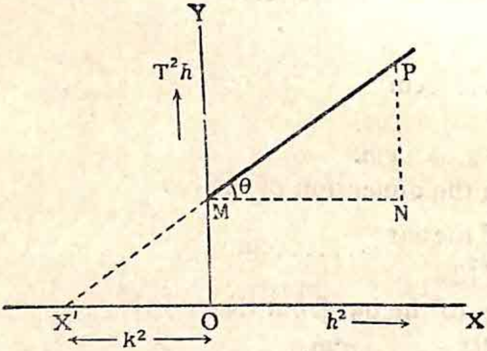
(3) The position of c.g. from the end A of the bar $= \ldots\ldots$ cm.

Precautions. (1) The knife-edge should be horizontal, or else the bar may slip off the knife-edge. (ii) Begin noting the time of oscillation after 5 or 6 oscillations by which time irregular motion of the pendulum will have subsided.

Discussion. This experiment gives a very satisfactory value of g. The value of g obtained from the minima points on the $(d-T)$ graph will be more accurate than that obtained from any other point on the curve. The reason is that at these points the slight error in the measurement of d produces the least effect on the value of T. But, as the holes have a finite radius, the exact points of minimum time-period cannot be correctly ascertained. For greater accuracy, the time-period has to be corrected for (i) finite arc of swing, (ii) curvature of knife-edge, (iii) yielding of the support and (iv) air effects.

Note. (i) From eqn. (1), $T^2h = \frac{4\pi^2}{g}h^2 + \frac{4\pi^2}{g}k^2 \quad .. \quad (6).$

So a graph of T^2h against h^2 will be a straight line. The slope $\left(\tan\theta = \frac{PN}{MN}\right)$ of this curve will give $\frac{4\pi^2}{g}$ and the intercept on the x-axis will give the value of k^2.



(Fig. 1.9)

To know h, locate also the position of the c.g. of the bar by balancing it on a sharp knife-edge (or wedge). Measure the distance (h_0) of c.g. from the same end A of the bar by a scale. Subtracting d from h_0, find out the distance h of the point of suspension from c.g. of the bar. Now plot the above graph taking only the positive value of h (i.e. when the points of suspension are on one side of c.g.).

From the graph, find the value of g and k. This graphical method is more *reliable and accurate* than the former one.

(ii) Having found k, the *moment of inertia* of the bar about the c.g. can be determined after having obtained its mass M by weighing;

$$I_G = Mk^2.$$

(iii) By this expt. we study the variation of T with d (or h) for a bar pendulum (compound pendulum).

EXPERIMENT 6. **Determination of 'g' by Kater's reversible pendulum.**

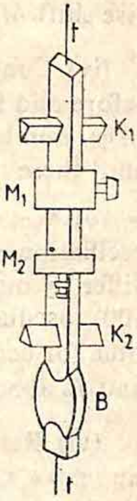
Apparatus. Kater's pendulum, stop watch, metre scale telescope, and an extra knife-edge (or a wedge).

Description of the apparatus : KATER'S PENDULUM. It consists of a metal rod about one metre long, at the ends of which there are two parallel knife-edges K_1 and K_2 facing towards each other. There is a heavy bob B at one end, this bob shifts the c.g. of the rod towards its side. There are two movable unequal weights M_1 and M_2 by shifting which the c.g. of the rod can be changed. The smaller weight M_2 has a micrometer arrangement for finer adjustment of its position.

In modern form of the apparatus the knife-edges K_1 and K_2 are fixed and the distance between them is accurately known. The pendulum may be set to ocillate about any one of the two knife-edges by placing them on agate plane firmly fixed to a rigid support.

Theory. If by adjustment, the periods of oscillation about both the knife-edges of a Kater's pendulum are made equal, say T, then the distance L between these two knife-edges would be the length of an equivalent simple pendulum and hence acceleration due to gravity g is given by

$$g = 4\pi^2 L/T^2 \quad .. \quad (1).$$



(Fig. 1.10)

But in practice, the exact equality of periods is not necessary. If the periods T_1 and T_2 about the two knife-edges are *very nearly equal*, then by measuring the distances l_1 and l_2 of the two knife-edges from the c.g. of the pendulum, the value of g can be computed, using Bessel's formula, as

$$\frac{8\pi^2}{g}=\frac{T_1^2+T_2^2}{l_1+l_2}+\frac{T_1^2-T_2^2}{l_1-l_2} \quad .. \quad (2).$$

Procedure. (i) Suspend the pendulum about the knife-edge K_1, so that the bob B is in the downward position. Focus sharply the lower tail t of the stationary pendulum in a telescope fitted at a distance, so that there is no parallax between the images of the tail and the vertical cross-wire which has already been focussed. If the pendulum is not provided with the tail, then draw a sharp white line along the length of the pendulum and focus this line in the telescope.

(ii) Oscillate the pendulum freely with small amplitude (3° to 4°) and note down the time for 5 oscillations by an accurate stop-watch (which can read up to one-tenth of a second). Suspend the pendulum about K_2 and note down again the time for 5 oscillations. Usually these two times will differ much.

(iii) Shift the position of the heavier adjustable mass M_1 in one direction and note down again the times for 5 oscillations about K_1 and K_2. If the difference between these two times decreases, then shift M_1 in the same direction in subsequent adjustments, otherwise shift M_1 in the opposite direction.

(iv) Continue the adjustment of M_1 in the same direction as before and for each position of M_1 find out times for gradually large number of oscillations (say 10, 15, 20, etc.) about K_1 and K_2 until these two times are nearly equal.

(v) Make finer adjustments with M_2 until the times for 50 oscillations about K_1 and K_2 are very nearly equal (they should not differ by more than 2 seconds). Now note down the tine for 50 (or 100) oscillations thrice for. each knife-edge and divide their mean time for each knife-edge by 50 (or 100) giving the time periods T_1 and T_2 about the knife-edge K_1 and K_2 respectively.

(vi) Remove the pendulum from its support and balance it on an extra knife-edge placed on the table. Mark the position of this knife-edge with a pencil, this mark gives the position of the c.g. of the pendulum. Measure the distances l_1 and l_2 of K_1 and K_2 respectively from this pencil mark by a metre scale. Thus knowing T_1, T_2, l_1 and l_2, calculate the vaule of g from the relation (2).

Observations

(A) *Times of oscillations at the preliminary observations.*

No. of obs.	Adjustments by shifting	No. of Oscillations	Times for oscillation about the knife-edges	
			K_1	K_2
			t_1	t_2
1	M_1 (heavier mass)	5	......min......sec.	......min......sec.
2		5	......min......sec.	......min......sec.
3		10	......min......sec.	......min......sec.
4		10	......min......sec.	......min......sec.
5		15	......min......sec.	......min......sec.
6		15	......min......sec.	......min......sec.
7	M_2 (smaller mass)	20	......min......sec.	......min......sec.
8		20	......min......sec.	......min......sec.
etc.	etc.	etc.	etc.	etc.

(B) *Final times of oscillations when t_1 and t_2 are very nearly equal.*

No. of obs.	Oscillations about the knife-edge	Times for 50 oscillations	Mean time	Time period
1	K_1	......min......sec.	......min......sec.	......sec. $=T_1$
2		......min......sec.	......min......sec.	
3		......min......sec.	......min......sec.	
1	K_2	......min......sec.	......min......sec.	......sec. $=T_2$
2		......min......sec.	......min......sec.	
3		......min......sec.	......min......sec.	

(C) *Distance between the c.g. of the pendulum and knife-edges.*

No. of obs.	Distance between the c.g. of the pendulum and the knife-edge				l_1+l_2 in cm	l_1+l_2 in cm
	K_1 (l_1) in cm	Mean l_1 in cm	K_2 (l_2) in cm	Mean l_2 in cm		
1	(...)−(...)=...	......	(...)−(...)=...	......	......	......
2	(...)−(...)=...		(...)−(...)=...			
3	(...)−(...)=...		(...)−(...)=...			

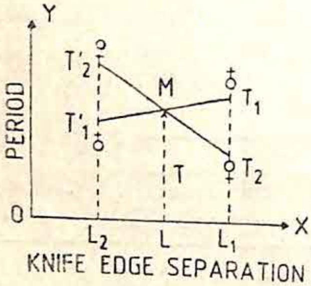
Calculations.

$$\frac{8\pi^2}{g}=\frac{T_1^2+T_2^2}{l_1+l_2}+\frac{T_1^2-T_2^2}{l_1-l_2}=\ldots.$$

or $$g=\ldots.\text{cm/s}^2=\ldots.\text{ms}^{-2}.$$

Precautions. (i) The two knife-edges should be made horizontal and parallel to each other. (ii) The amplitude of oscillation should be made small so that the formula used may hold good. (iii) A very accurate stop-watch should be used. (iv) In the preliminary observations the difference in the times of oscillation about the two knife-edges is very large and hence times for smaller number of oscillations should be noted to save time.

Discussions. (i) In the older form of the apparatus, in which one of the knife-edges is movable, the exact distance L between the two knife-edges at which the two time periods would be equal can be found out graphically as described below. But the disadvantages are (a) that the two knife-edges would not remain always parallel, and (b) the distance between the knife-edges is to be measured for every adjustment.



(Fig. 1.11)

Suppose K_1 is adjustable and it is so adjusted that time period T_1 about K_1 is *slightly greater* than the period T_2 about K_2. Measure the distance L_1 between K_1 and K_2. Now move K_1 towards K_2 until the period T_1' about K_1 is *slightly smaller* than the period T_2' about K_2. Measure again the distance L_2 between K_1 and K_2. On a graph paper plot the distance between the knife-edges along x-axis and the periods about K_1 and K_2 along y-axis (Fig. 1.11). Join the points (L_1, T_1) and (L_2, T_1') giving the straight line T_1T_1'. Also join the points (L_1, T_2) and (L_2, T_2') giving the straight line T_2T_2'. Find the coordinates of the point of intersection M of these two straight lines, viz. (L, T), which on substitution in relation (1) gives the value of g.

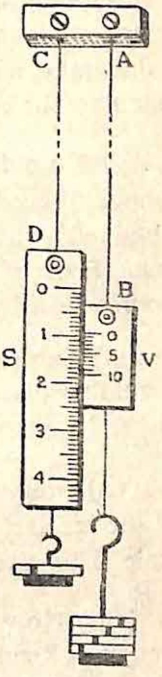
(ii) For greater accuracy, the time period should be determined by *coincidence method.*

ELASTICITY

EXPERIMENT 7. Determination of Young's modulus of elasticity by the Vernier apparatus.

Apparatus. Vernier apparatus, slotted weights, screw gauge, measuring tape, rough balance and weight-box.

Description of the apparatus : VERNIER APPARATUS. It consists of two long wires of the same material suspended side by side from the same support. One of the wires has the main scale of a vernier arrangement attached to it and the other the movable vernier scale. The vernier carries at its lower end a hook or pan on which stretching loads are placed. The wire *CD* is also kept stretched by a constant load. This arrangement obviates any error due to temperature changes during experiment or yielding of the support, from affecting the observed elongation of the experimental wire *AB*.



(Fig. 1.12)

Theory. If a wire of length L cm and radius r cm is stretched by applying a load of M gm at its free end and undergoes an elongation of l cm then,

$$\text{Young's modulus, } Y = \frac{\text{Longitudinal stress}}{\text{Longitudinal strain}}$$

$$= \frac{Mg/\pi^2}{l/L} \text{ dynes/cm}^2,$$

where g is the acceleration due to gravity in cm/sec/sec.

Procedure. (i) Weigh each slotted weight in a rough balance.

(ii) Place slotted weight of 1 or 2 kgm (or more if necessary) on the hangers attached to each of the wires (if such weights are not there) to keep them taut and free from kinks*. Record this load on

---

*Best method of removing kinks is to place the maximum permissible load (including the dead load) on the hanger of the wire and waiting for a few minutes. Remove the greater part of the weight leaving enough to keep the wire taut. To test this read the position of the *zero* of the vernier. Put a wt. of about $\frac{1}{2}$ kgm and then unload it. Again read the zero of the vernier. If the wire is taut the two readings will agree.

the experimental wire AB as "*dead load*" which need not be used in calculations. Remove the elastic fatigue of the experimental wire by loading and unloading the wire alternately.

(iii) Measure the length of the wire AB between the point of suspension (A) and the point of the wire at which the vernier is fixed (B) by means of a tape. Repeat it three times and find the mean L in cm.

(iv) Carefully measure the diameter of the wire AB by a screw gauge at several points (at least 10) along its length and at each point take both direct and cross readings. Find the mean and calculate the cross-section of this wire, in square cm.

(v) Note down the *breaking stress* for the material of the wire from a book of constants and multiply it by cross-section. The value so obtained is the load which will *snap* the wire and is called the *breaking load.* Half of this is the *maximum permissible load* (also called the *limiting load*) which can be applied to the wire.

(vi) Subtract dead load from the limiting load and divide this into a number of equal instalments (nearly 10) so that each instalment is either 1 kgm or $\frac{1}{2}$ kgm (approx.).

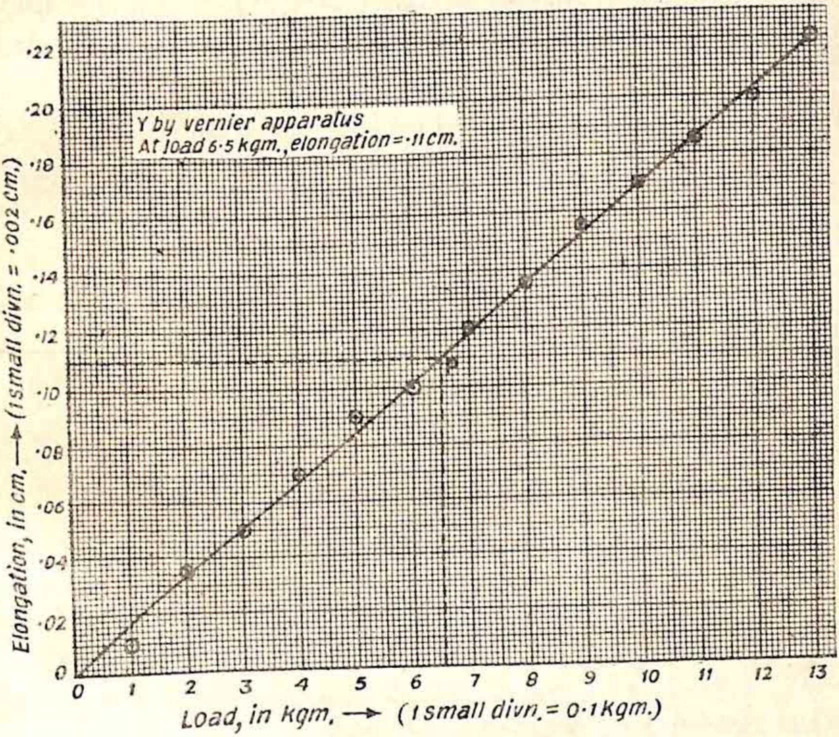
(vii) Find out the value of one scale division and the least count of the vernier. Note the position of the *zero of the vernier* over the scale. This gives the initial reading.

(viii) Now load the wire AB *gently* with the first instalment of weight. Read the position of the zero of the vernier over the scale *after waiting for about a minute* to allow the elongation to assume a steady value. Increase the load of the wire by equal instalment of weight, taking the reading of the zero of the vernier after each addition to the load till the maximum permissible load (including the dead load) is reached. Write the readings in the column *load increasing*. *While increasing load, at no time should the load be decreased.*

(ix) Now decrease the load stepwise as before and read the zero of the vernier each time. Write the readings in the column *load decreasing*. The weight should be removed till the wire is stretched by the dead load only. *While decreasing load, at no time should the load be increased.*

(x) For each load, find the mean of the two readings, one for the load increasing and another for the load decreasing. Next find out the elongations for various loads by subtracting the initial reading from the corresponding mean reading.

(xi) Plot a graph taking load in kgm along the x-axis and elongation in cm along the y-axis. The origins for both should be zero. The resulting graph will be a straight line passing through the origin (Fig. 1.13.). Take a suitable point (say, P) on the graph and find out the coordinates of this point (which should not be within the data). From the values thus obtained, calculate Y.



(Fig. 1.13)

Observations and Calculations

Enter thus—Material of the wire—steel.

(A) *Dead load* = ... kgm.

(B) *Length of the wire* :

(i) ....cm, (ii)..........cm, (iii) ....cm.

Mean $L = 83{\cdot}9 \times 2{\cdot}54$ cm.

(C) *Reading for the cross-section of the wire.*

Pitch of the screw gauge = ...cm.

No. of circular scale divisions = ...

Least count of the screw gauge = ...cm.

Zero-error = ± ....cap div. [If the error is zero, state 'nil'.]

No. of obs.	No. of complete rotn.	Complete rot.× Pitch (cm)	Cap. reading	Corrected cap. reading	Corr. cap. read.× L.C.	Total (cm)	Mean diam. (cm)	Mean radius, *r* (cm)
1. D.	...	...	...	...	...	...	...	0·0449
1. C.	...	...	...	...	...	...	...	
2. D.	...	...	...	...	...	...	...	
2. C.	...	...	...	...	...	...	...	
: :								
10. D.	...	...	...	...	...	...	...	
10. C.	...	...	...	...	...	...	...	

∴ Area of cross-section $= \pi r^2 = 0{\cdot}0063$ sq. cm.

(D) *Breaking load.*

Breaking stress = 8000 kgm wt./cm^2.

∴ Breaking load = cross-section × breaking stress

$= 0{\cdot}0063 \times 8000$ kgm wt.

∴ Limiting load $= \frac{1}{2} \times$ breaking load = 25 kgm wt. (approx).

(E) *Reading for elongation versus load.*

1 main scale division = ...cm.

........vernier divisions coincide with......M.S. divns.

∴ Vernier divn. = ...cm.

∴ Least count = 1 M.S. − 1 v. = 0·01 cm.

No. of obs.	Load in gm (excess of the dead load)	Reading for the elongation							Elongation in cm	Elong. in cm. for 5 kgm
		Load increasing			Load decreasing			Mean in cm		
		M.S. in cm	Ver.	Total in cm	M.S. in cm	Ver.	Total in cm			
1	0	2·1	9	2·19	2·1	9	2·19	2·19	0	
2	1	2·2	0	2·20	2·2	0	2·20	2·20	0·01	
3	2	2·2	3	2·23	2·2	2	2·22	2·225	0·035	
4	3	2·2	4	2·24	2·2	4	2·24	2·24	0·05	
5	4	2·2	6	2·26	2·2	6	2·26	2·26	0·07	
6	5	2·2	8	2·28	2·2	8	2·28	2·28	0·09	0·09
7	6	2·2	9	2·29	2·2	9	2·29	2·29	0·10	0·09
8	7	2·3	1	2·31	2·3	1	2·31	2·31	0·12	0·085
9	8	2·3	3	2·33	2·3	2	2·32	2·325	0·135	0·085
10	9	2·3	4	2·34	2·3	5	2·35	2·345	0·155	0·085
11	10	2·3	6	2·36	2·3	6	2·36	2·36	0·17	0·08
12	11	2·3	7	2·37	2·3	8	2·38	2·375	0·185	0·085
13	12	2·3	9	2·39	2·3	9	2·39	2·39	0·20	0·08
14	13	2·4	1	2·41	2·4	1	2·41	2·41	0·22	0·085

$$\therefore \quad \text{Mean elongation } l=\frac{\begin{array}{r}0{\cdot}09+0{\cdot}09+0{\cdot}085+0{\cdot}085+0{\cdot}085+0{\cdot}08\\ +0{\cdot}085+0{\cdot}08+0{\cdot}085\end{array}}{9}$$

$$=0{\cdot}085 \text{ cm};$$

for load $M=5 \text{ kgm} = 5000 \text{ gm}$.

$$\therefore \qquad Y=\frac{Mg/\pi r^2}{l/L}=\frac{5000\times 980}{3{\cdot}1416\times(0{\cdot}0449)^2}\div\frac{0{\cdot}085}{83{\cdot}9\times 2{\cdot}54}$$

$$=19{\cdot}39\times 10^{11} \text{ dynes/cm}^2=19{\cdot}39\times 10^{10} \text{ N m}^{-2}.$$

From graph (see Fig. 1.13),

elongation $=0{\cdot}11$ cm,
for load $=6{\cdot}5$ kgm $=6500$ gm.

$$\therefore \quad Y=\frac{6500\times 980\times 83{\cdot}9\times 2{\cdot}54}{3{\cdot}1416\times(0{\cdot}0449)^2\times 0{\cdot}11}=19{\cdot}48\times 10^{11} \text{ dynes/cm}^2.$$

$$=19{\cdot}48\times 10^{10} \text{ N m}^{-2}$$

Result. $Y=19{\cdot}39\times 10^{10}$ N m^{-2} (from calculation)
$=19{\cdot}48\times 10^{10}$ N m^{-2} (from graph).

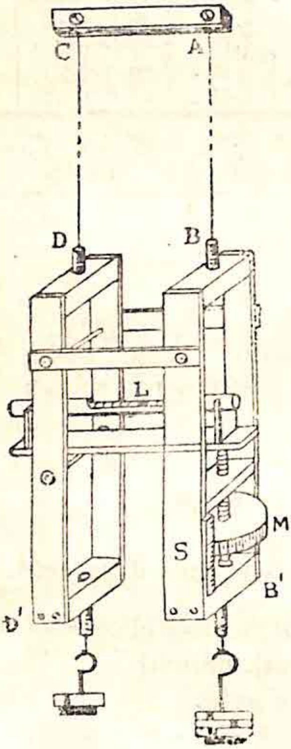
Standard value $=19{\cdot}5-20{\cdot}6\times 10^{10}$ N m^{-2}.

Precautions. (i) Every time wait for about a minute after a load is added or removed before taking the reading. (ii) While taking readings take care that the suspended system is at rest in equilibrium. Do not twist the system. (iii) The constant load on the auxiliary wire *CD* and the dead load on *AB* should be sufficient to keep the wires taut and free from kinks. (iv) While calculating elongation for various loads the difference between consecutive reading should never be taken but difference between the 6th and the 1st, 7th and 2nd and so on be taken. This will enable all the readings to be utilized. (v) While using the screw gauge care should be taken to avoid back-lash error.

EXPERIMENT 8. **Determination of Young's modulus of elasticity by Searle's apparatus.**

Apparatus. Searle's apparatus, slotted weights, screw gauge, measuring tape, rough balance and weight-box.

Description of the apparatus : SEARLE'S APPARATUS. It consists of two long wires of the same material suspended side by side from the same support. The lower ends of the wires carry the rectangular frames BB' and DD' hinged together by two cross-pieces so that the wires can move freely relative to each other in a vertical direction. Inside the frame, there is a sensitive spirit level L fixed to a plane base, one end of which is pivoted to a horizontal bracket fixed to the frame DD' and the other end rests on the pointed end of the micrometer screw M working in the same vertical line as the experimental wire AB. The micrometer screw is provided with a graduated head whose movements can be read over a linear scale S. To the lower ends of the frame-work are attached two hooks on which weights can be placed. Here the elongation of the experimental wire AB is measured by the micrometer screw.



(Fig. 1.14)

Theory. Same as in Expt. 7.

Procedure. (i) Repeat the operations (i), (ii), (iii)*, (iv), (v) and (vi) of the previous experiment.

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* Here the length of the ezperimental wire to be measured is between the points of suspension and the point where it is fixed to the frame.

(ii) Find out the value of one linear scale division, the pitch and the least count of the micrometer attached to the frame. Adjust the micrometer screw until the air-bubble is at the centre of the spirit level. Note the readings on the linear scale and the circular scale. This gives the intial reading.

(iii) Now load the wire *AB gently* with the first instalment of weight. After waiting for about a minute to allow the elongation to assume a steady value, adjust the micrometer screw till the bubble is brought back to the centre. Note the readings of the micrometer. Increase the load of the wire by equal instalment of weight taking the readings of the micrometer after each addition to the load till the maximum permissible load (including the dead load) is reached. *While increasing load, at no time should the load be decreased.*

(iv) Now decrease the load stepwise as before and note the reading of the micrometer each time. The weight should be removed till the wire is stretched by the dead load only. *While decreasing load, at no time should the load be increased.*

(v) Repeat the operations (x) and (xi) of the previous experiment.

Observations and Calculations

Enter thus—

Material of the wire—copper.

(A) *Dead load*= .... kgm.

(B) *Length of the wire*

(i) ...... cm, (ii) ...... cm, (iii) ...... cm.

Mean, $L=99{\cdot}6\times2{\cdot}54$ cm.

(C) *Reading for the cross-section of the wire*

Pitch of the screw gauge = ... cm.

No. of circular scale divisions = ...

Least count = ... cm.

Zero-error = ± . . . . Cap. divn. [If the error is zero, state 'nil'.]

Now tabulate the data as in Expt. 7.

∴ Mean radius $r = 0{\cdot}046$ cm.

∴ Area of cross-section $= \pi r^2 = 0{\cdot}00664$ sq. cm.

(D) *Breaking load.*

Breaking stress = 3000 kgm wt./cm².

∴ Breaking load = 0·00664 × 3000 kgm wt.

∴ Limiting load = 9·92 kgm wt. (approx).

(E) *Reading for elongation versus load.*

1 Linear scale division = 0·1 cm.

Pitch of the micrometer screw = 0·05 cm.

No. of circular scale divisions = 50.

Least count of the micrometer = 0·001 cm.

No. of obs.	Load in gm (excess of the dead load)	Readings for the elongation							Elongation in cm	Elongation in cm for 2500 gm
		Load increasing			Load decreasing			Mean in cm		
		L.S. in cm	C.S.	Total in cm	L.S. in cm	C.S.	Total in cm			
1	0	0	50+25	·075	0	50+31	·081	·078	·0	
2	500	0	50+49	·099	·1	1	·101	·101	·022	
3	1000	·1	12	·112	·1	14	·114	·113	·035	
4	1500	·1	25	·125	·1	25	·125	·125	·047	
5	2000	·1	37	·137	·1	39	·139	·138	·060	
6	2500	·1	50+3	·153	·1	50+5	·155	·154	·076	
7	3000	·1	50+17	·167	·1	50+19	·169	·168	·090	·076
8	3500	·1	50+31	·181	·1	50+33	·183	·182	·104	·058
9	4000	·1	50+4	·196	·1	50+48	·198	·197	·119	·069
10	4500	·2	12	·212	·2	14	·214	·213	·135	·072
11	5000	·2	28	·228	·2	28	·228	·228	·150	·075
										·074

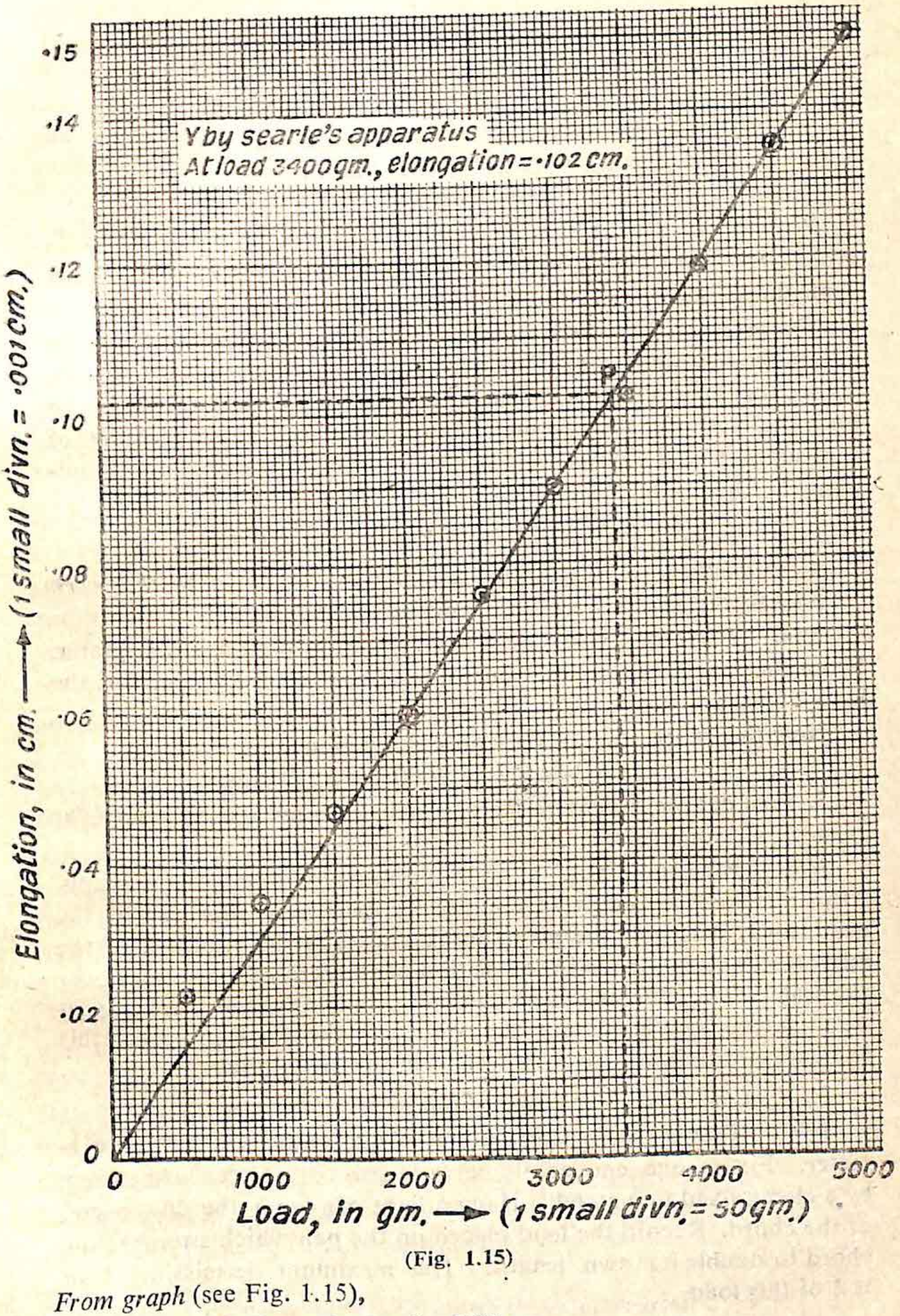
$$\therefore \text{Mean elongation } l = \frac{0{\cdot}076 + 0{\cdot}068 + 0{\cdot}069 + 0{\cdot}072 + 0{\cdot}075 + 0{\cdot}074}{6}$$

$$= 0{\cdot}0723 \text{ cm};$$

for load $M = 2500$ gm.

$$\therefore \quad Y = \frac{Mg/\pi r^2}{l/L} = \frac{2500 \times 980 \times 99{\cdot}6 \times 2{\cdot}54}{0{\cdot}00664 \times 0{\cdot}0723}$$

$$= 12{\cdot}9 \times 10^{11} \text{ dynes/cm}^2 = 12{\cdot}9 \times 10^{10} \text{ Nm}^{-2}.$$



(Fig. 1.15)

From graph (see Fig. 1.15),

Elongation = 0·102 cm; for load = 3400 gm.

$$\therefore \quad Y=\frac{3400\times 980\times 99{\cdot}6\times 2{\cdot}54}{0{\cdot}00664\times 0{\cdot}102}=12{\cdot}4\times 10^{11} \text{ dynes/cm}^2$$

$$=12{\cdot}4\times 10^{10} \text{ Nm}^{-2}.$$

Result. $Y=12{\cdot}9\times 10^{10}$ Nm^{-2} (from calculation)
$=12{\cdot}4\times 10^{10}$ Nm^{-2} (from graph).

Standard value $=12{\cdot}4-12{\cdot}9\times 10^{10}$ Nm^{-2}.

Precaution. In addition to the precautions given in Expt. 7, avoid *back-lash error* by rotating the micrometer screw always in the same direction.

Discussion. As the spirit level is very sensitive, it enables one to adjust the micrometer screw at least up to half of a circular division. Hence this method is decidedly superior to the Vernier method. In both the methods, the two main sources of error due to yielding of the support and change of temperature have been completely eliminated by the use of the auxiliary wire.

ASSOCIATED EXPERIMENTS

1. *Draw the load-elongation graph and hence calculate the work done when the wire is stretched by a load of* 2·5 *kgm.*

Hint. Perform Expt. 8 or 7 and draw load-elongation graph. From the graph, obtain the value of the elongation, l, in cm for the load 2·5 kgm.

Now the work done $=\frac{1}{2}\times$load$\times$elongation
$=\frac{1}{2}\times 2{\cdot}5\times 1000\times 980\times l$ ergs.

2. *Find out the weight of the given brick using Young's modulus apparatus.*

Hint. Perform Expt. 8 or 7 and draw load-elongation graph. After removing all weights from the experimental wire except the dead load, suspend the given brick and take the readings of the micrometer screw or read the position of the zero of the vernier over the scale. The difference with the initial reading gives the elongation. From graph, obtain the value of the load in kg for this elongation which will give the weight of the given brick.

3. *Find the Young's modulus of rubber.*

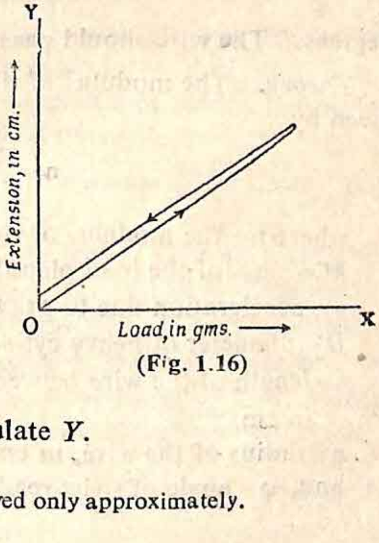
Hint. Take a rubber chord about 50 cm long and 5 mm in diameter. Fix its one end tightly between two cork pieces held closely by a clamp fixed to a stand. Hang a light pan from the lower end of the chord. Record the load placed on the pan which stretches the chord to double its own length. The maximum permissible load is $\frac{1}{2}$ of this load.

Insert two pins in the chord about one inch away from each end. Put some weight on the pan to keep the chord stretched. Record this load as "dead load" which need not be used in calculation. Now measure the distance between the two pins by means of a cathetometer telescope (or microscope). This is the length *L*.

Load the pan *gently* with the first instalment of weight. The positions of the two pins will be shifted. Measure the distance between the pins. The difference with the former distance gives the elongation for this load. Increase the load of the chord by equal instalment of weight, measuring the distance between the pins after each addition of load, till the maximum permissible load is reached. The number of equal instalments should be nearly ten. Find out the elongation for various loads.

Now decrease the load stepwise as before and measure the distance between the pins each time. Again find out the elongation for various loads. Find the diameter of the chord at several points along its length by means of a travelling microscope. Both direct and cross readings should be taken. Calculate the area of cross-section.

Plot a graph taking increasing load along the x-axis and corresponding elongation along the y-axis. The resulting graph will be a straight line (slightly curved)* passing through the origin. On the same graph paper again plot a graph taking decreasing load along the x-axis and corresponding elongation along the y-axis. The graph will not return along the same path but every elongation will be greater than what it had been for the particular load for increasing load. Also this graph will have a positive interception on the y-axis, which shows that when weights are taken off, the original length has slightly increased.



(Fig. 1.16)

From the graph, obtain elongation for a particular load and calculate *Y*.

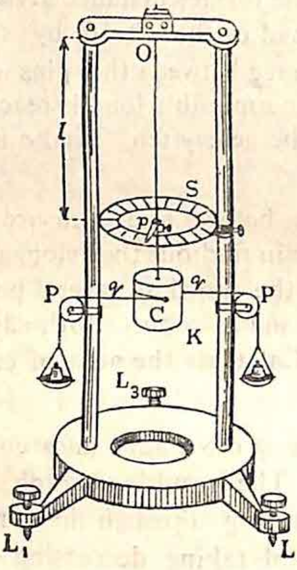
---

*This shows that the Hooke's law is obeyed only approximately.

EXPERIMENT 9. Determination of the modulus of rigidity of a wire by statical method using Barton's apparatus.

Apparatus. Barton's apparatus, slide callipers (big), screw gauge, two weight boxes, metre scale and spirit level.

Description of the apparatus : BARTON'S APPARATUS. It consists of a rigid metal frame on levelling screws (L_1, L_2, L_3). The experimental wire is fixed to a rigid support O at the top of the frame and carries a heavy metal cylinder K (called the *fly-wheel*). This keeps the wire taut and straight. Two strings $q\,q$ attached to a peg C on the cylinder are wound on K in the *same* direction and then made to pass over two small frictionless pulleys P—P fixed on the frame at diametrically opposite points with respect to K. Two pans or hangers are attached to the free ends of the strings. A couple is applied to the cylinder by placing equal weights in the pans as a result of which the wire is twisted. The angle of twist is read by a pointer attached to the wire near its lower end moving over a horizontal circular scale S graduated in degrees. The wire should pass through the centre of this scale.



(Fig. 1.17)

Theory. The modulus of rigidity of the material of the wire is given by

$$\eta = \frac{360.Mg.D.l}{\pi^2 r^4 \,\varphi},$$

where η = the modulus of rigidity in dynes per sq. cm,
M = mass of the load placed in each of the pans, in gm,
g = acceleration due to gravity in cm/sec^2,
D = diameter of heavy cylinder, in cm,
l = length of the wire between the fixed end O and the pointer p, in cm,
r = radius of the wire, in cm
and, φ = angle of twist read by the pointer, in degrees.

Procedure. (i) Level the apparatus by placing a spirit level on the circular scale such that it is parallel to the line joining two of the levelling screws and adjust any one of the two screws until the bubble is at the centre of the spirit level. Next place the spirit level at right angles to the former position and bring back the bubble at the centre by adjusting the third screw only. This ensures that the experimental wire passes through the centre of the circular scale.

(ii) Measure the length of the wire between the fixed end and the pointer. Repeat it three times and find the mean l in cm.

(iii) Carefully measure the diameter of the wire by a screw gauge at several points (at least 10) along its length and at each point take both direct and cross-readings. Find the mean and hence find the radius (r) in cm. As the expression for η involves the fourth power of r, an error of 1% in the radius measurement will cause an error of 4% in the final result. Hence it should be measured very carefully.

(iv) Measure the diameter of the cylinder by slide callipers. Repeat it three times and find the mean diameter D in cm.

(v) Adjust the pointer so that it reads zero. The pointer should *just* touch the circular scale. If the pointer is not adjustable, note the pointer reading.

(vi) *Gently* place equal loads like 0·5, 1, 1·5, 2, 2·5, 3 kgm etc. in each of the two pans and note the corresponding pointer readings* after *waiting for about a minute* every time.

(vii) Now decrease the loads in equal steps as before till the original condition of no load in the pans is reached and note the readings of the pointer after each decrease of load. Before taking readings wait for about a minute each time.

(viii) From these two sets of observations find the mean twist for each load.

(ix) Plot a graph taking load in gm along the x-axis and twist in degrees along the y-axis (fig. 1.18). The resulting graph will be a straight line passing through the origin. The origins for both should be zero. From a point P on the graph, as far away from the origin as is convenient, find the twist and the corresponding load. Substitute this value of M/φ in the formula for η and hence calculate η.

---

*If possible read both the ends of the pointer to avoid the error due to eccentricity.

Observations and Calculations

Enter thus—

Material of the wire—copper.

(A) *Length of the wire* :

(i)...........cm, (ii).. ....cm, (iii).........cm.

Mean, $l = 83{\cdot}5$ cm.

(B) *Readings for the diameter of the wire.*

Pitch of the screw gauge = ...cm.

No. of circular scale divisions = ...

Least count of the screw gauge = ...cm.

Zero-error = ± ......cap. divn. (If the error is zero, state 'nil'.)

Now tabulate the data as in Expt. 7.

$\therefore$ Mean radius of the wire, $r = 0{\cdot}2406$ cm.

(C) *Readings for the diameter of the cylinder.*

1 main scale division = 0·1 cm.

10 vernier divns. coincide with 9 M. S. divns.

$\therefore$ 1 vernier division $= \frac{9}{10} \times 0{\cdot}1 = 0{\cdot}09$ cm.

$\therefore$ Least count of the slide callipers $= 0{\cdot}1 - 0{\cdot}09 = 0{\cdot}01$ cm.

Zero-error = ± ......cm.

No. of obs.	M.S. (cm)	Ver.	Total (cm)	Mean diam. (cm)	Corrected diam. (cm)
1. D.	...	...	...		
C.	...	...	...		
2. D.	...	...	...	...	...
C.	...	...	...		
3. D.	...	...	...		
C.	...	...	...		

∴ Diameter of the cylinder, $D = 5{\cdot}35$ cm.

Acceleration due to gravity, $g = 980$ cm/sec/sec.

(D) *Readings for load versus twist.*

No. of obs.	Load on each pan M, in kgm	Pointer readings, in degrees			Twist, φ in deg.	Twist in deg. for 2·0 kgm
		Load increasing	Load decreasing	Mean		
1	0	4·5	4·5	4·5	0	
2	·5	10·8	12·0	11·4	6·9	
3	1·0	15·2	18 0	16·6	12·1	
4	1·5	22	26	24	19·5	
5	2·0	27·2	31·0	29·1	24·6	24·6
6	2·5	34	36·2	35·1	30·6	23·7
7	3·0	40	43	41·5	37·0	24·9
8	3·5	46	46	46	41·5	22·0

∴ Mean twist, $\varphi = 23{\cdot}8$ deg. for load, $M = 2{\cdot}0$ kgm $= 2000$ gm.

$$\therefore\ \eta = \frac{360\ Mg.D.l}{\pi^2.r^4.\varphi}$$

$$= \frac{360 \times 2000 \times 980 \times 5{\cdot}35 \times 83{\cdot}5}{(3{\cdot}1416)^2 \times (0{\cdot}2406)^4 \times 23{\cdot}8} = 4{\cdot}0 \times 10^{11}\ \text{dynes/sq. cm}$$

$$= 4{\cdot}0 \times 10^{10}\ \text{Nm}^{-2}.$$

From graph (Fig. 1.18),

Twist $= 34$ deg., for load $= 2{\cdot}75$ kgm $= 2750$ gm.

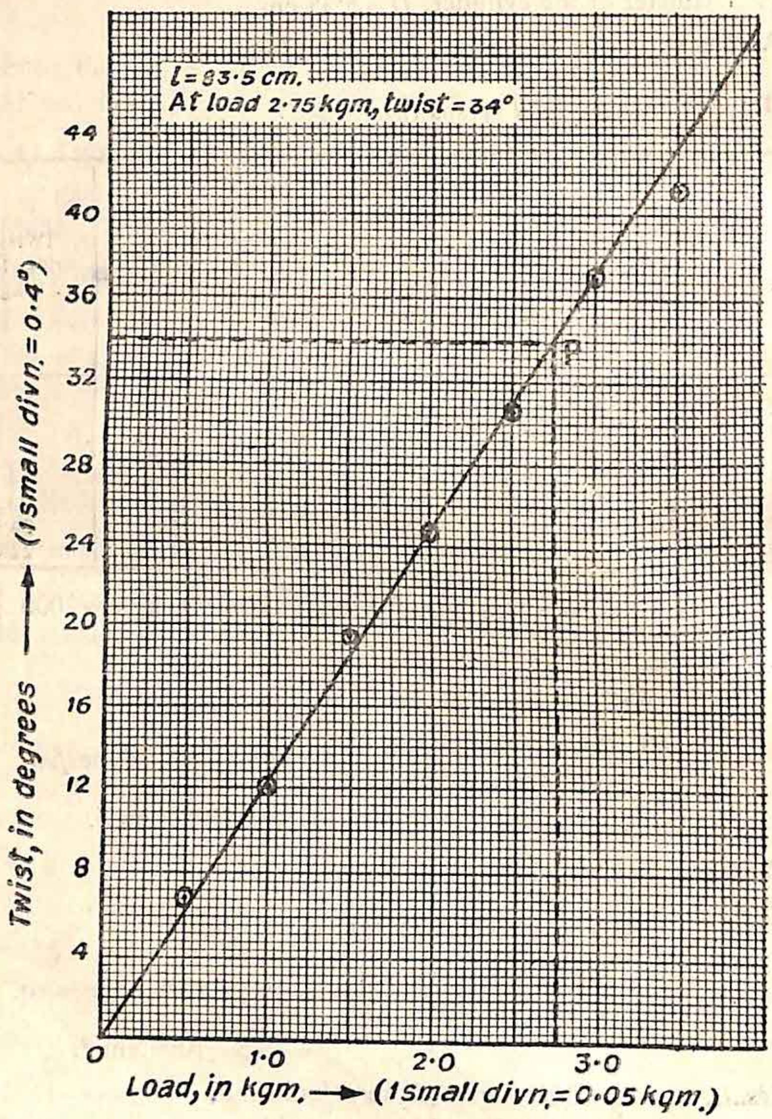
$$\therefore\ \eta = \frac{360 \times 2750 \times 980 \times 5{\cdot}35 \times 83{\cdot}5}{(3{\cdot}1416)^2 \times (0{\cdot}2406)^4 \times 34} = 3{\cdot}85 \times 10^{11}\ \text{dynes/sq. cm}$$

$$= 3{\cdot}85 \times 10^{10}\ \text{Nm}^{-2}.$$

Result. $\eta = 4{\cdot}0 \times 10^{10}\ \text{Nm}^{-2}$ (from calculation)
$= 3{\cdot}85 \times 10^{10}\ \text{Nm}^{-2}$ (from graph).

Standard value $= 3{\cdot}9 - 4{\cdot}0 \times 10^{10}\ \text{Nm}^{-2}$.

Precaution. (i) While taking readings of the pointer, the system should be in equilibrium. (ii) Care should be taken to maintain the strings, leaving the cylinder horizontal otherwise the arm of the couple applied will not be equal to the diameter of the cylinder. (iii) The loads should never exceed the maximum permissible load. (iv) While using the screw gauge care should be taken to avoid backlash error.



(Fig 1.18)

Discussion. As the angle of twist is measured by the pointer over the circular scale, which is not a sensitive method, the accuracy is limited. Also if the strings used are not very thin the diameter of the pulley will be affected. If the pulleys are not frictionless, error will be introduced in the value of the force applied by means of the load and hence the result will be adversely affected.

Note. In some apparatus there are three (or two) pointers moving over the graduated circles. Here l_1, l_2 and l_3 are the distances of the pointers from the fixed end. For each couple applied the twists for the three lengths can be read *simultaneously*. Plot $(M\text{-}\varphi)$ graphs for each length of the wire. From these graphs find out the best value of φ, M corresponding to each l. Calculate η for each length and find out the mean value of η. Also plot a graph taking l along the x-axis and $\frac{\varphi}{M}$ along the y-axis. The graph will be a straight line which shows that the angle of twist is proportional to the length of the rod twisted. The modulus of rigidity can also be calculated by making use of this graph. By taking two suitable points lying on this graph, the difference between their abscissae will give (l_1-l_2) while the difference between their ordinates will give $(\varphi_1-\varphi_2)/M$. Thus we have,

$$\eta=\frac{360\ Mg\ D\ (l_1-l_2)}{\pi^2 r^4(\varphi_1-\varphi_2)}.$$

ASSOCIATED EXPERIMENT

1. *Show that the angle of twist for a given length of the wire is proportional to the couple applied to it.*

Hint. Draw $(M\ \varphi)$ graph.

EXPERIMENT 10. Determination of the modulus of rigidity by the dynamical method.

Apparatus. The given wire, a spherical ball, stand and clamp, stop-watch, screw-gauge, slide-callipers, balance, weight-box, telescope and metre scale.

Theory. The modulus of rigidity of the material of the wire is given by

$$\eta=\frac{8\pi l I}{r^4 T^2},$$

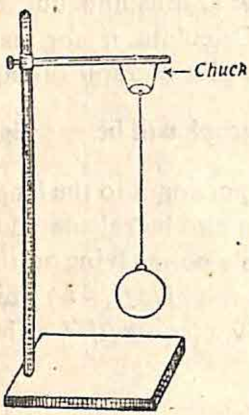
where η = the modulus of rigidity, in dynes/sq. cm;
r = the radius of the wire, in cm;
l = the length of wire, in cm;
T = the time period, in sec; and
I = the moment of inertia of the body about the axis of suspension.

If the body* used is a solid sphere of mass M and radius R, then $I=\frac{2}{5}MR^2$.

---

* If it is a cylinder then $I=\frac{1}{2}MR^2$. If it is a disc then $I=\frac{1}{2}MR^2$. If it is a cube then $I=\frac{1}{6}Ma^2$ where a is the side of the cube.

Procedure. (i) Take a wire about 50 cm long and 0·1 cm in diameter. Suspend the sphere from a rigid support by the given wire so that the axis of the wire passes through the centre of the sphere*. Enclose the suspended part in a case with a glass door to protect it from air draught.



(Fig. 1.19)

(ii) Make a vertical line on the sphere and focus a telescope till there is no parallax between its image and the vertical cross-wire. Twist the sphere about the axis of the wire through an angle of 60° and release it. It will execute angular oscillations. Damp out the *pendular oscillations* if there be any. Start the stop-watch when the vertical line crosses the cross-wire and measure the time for 50 oscillations. Repeat it three times and find the mean. Then find out the time period T in sec.

(iii) Measure the length (l cm) of the wire between the point of suspension and the point at which the wire is attached to the sphere.

(iv) Carefully measure the diameter of the wire by a screw gauge at several places (at least ten) and take both direct and cross readings at each place.

(v) Now take out the sphere and weigh it correct up to 0·1 gm. Also measure the diameter of the sphere by slide callipers and calculate the moment of inertia of the sphere about the axis of suspension.

(vi) Find out the time-periods for different lengths of the wire.

(vii) Draw a graph taking l in cm along x-axis and T^2 in sq. sec along y-axis, which will be a straight line passing through the origin. Find the *slope* of this graph which will give $\frac{8\pi I}{\eta r^4}$. From this calculate η.

Plot another graph with $\left(\frac{r^4}{l}\right)$ along the x-axis and T^2 along the y axis. This should be a rectangular hyperbola.

---

* If it is a cylinder then the wire should pass through the axis of the cylinder.

Observations and Calculations

Enter thus—

Material of the wire...........

(A) *Readings for the diameter of the wire.*

Pitch of the screw gauge = ...cm.

No. of circular scale divisions = ...

Least count = ...cm.

Zero-error = ± ....cap. div. (If the error is zero, state 'nil.)

Now tabulate the data as in Expt. 7.

∴ Mean radius of the wire, r = ...cm.

(B) *Readings for the diameter of the sphere.*

1 M.S. divn. of the slide callipers = ...cm.

....vernier divns. coincide with.......M.S. divns.

∴ 1 ver. div. = ...cm.

∴ Least count of the slide callipers = 1 M.S. − 1 ver.

= ....cm.

Zero-error = ± ....cm.

Now tabulate the data as in Expt. 9

∴ Radius of the sphere, R = ...cm.

(C) Mass of the given sphere, M = ...gm.

∴ Moment of inertia, $I = \frac{2}{5}MR^2$ = ...gm-cm².

(D) *Readings for length versus time period.*

No. of obs.	Length of the wire l, in cm	Time for 50 oscillations, in sec				Time period T in sec	T^2 in sec²	r^4/l in cm³.	η, in dynes/cm²	Mean η in dynes per sq. cm
		I	II	III	Mean					
1										
2										
3										
4										
5										

From $(l-T^2)$ graph, slope = ...
$\therefore$ η = ...dynes/sq. cm = ...N m^{-2}.
Result. η = ...dynes/sq. cm = ...N m^{-2} (from calculations)
= ...... ,, ,, ,, = ...N m^{-2} (from graph).
Standard value = ...

Precautions. (i) The wire should be fairly thin and long and free from kinks. (ii) See that the sphere executes only torsional oscillations. Any other motion should be stopped by a camel-hair brush. (iii) Since the restoring couple is proportional to the angle, the ratio of displacement to acceleration is constant for all angles, hence there is no restriction on the angular amplitude, particularly when the wire is *thin* and *long*. However, the twist should not be very large.

Discussion. In deriving the above formula for η it is assumed that the value of the couple per unit twist (angulur displacement) remains constant but this is not so, for the radius of the wire changes when it is loaded. Again the moment of inertia has been calculated from its dimensions on the assumption that the density of its material is uniform throughout its entire mass. This is seldom the case. This imperfection entails an error in the value of η. (These sources of error are eliminated by the use of Maxwell's needle.)

The moments of inertia of different bodies can be compared by this method. If T_1 and T_2 are the time-periods when the bodies of moments of inertia I_1 and I_2 are in turn attached to the wire,

then $T_1=2\pi\sqrt{\frac{I_1}{C}}$ and $T_2=2\pi\sqrt{\frac{I_2}{C}}$, where C = the couple per unit angular displacement.

Hence
$$\frac{I_1}{I_2}=\frac{T_1^2}{T_2^2}.$$

ASSOCIATED EXPERIMENT

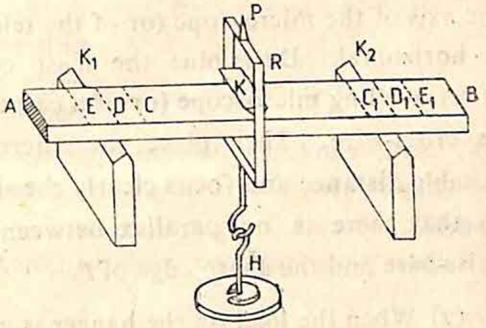
1. *Find the modulus of rigidity of glass.*

Hint. Draw a fairly long and thin glass fibre of uniform radius. Use this fibre in place of wire and a small wooden cube in place of sphere and perform the above experiment. Use lac for fixing the fibre to the centre of a face of the cube.

EXPERIMENT **11.** **Determination of the Young's modulus of a beam by bending.**

Apparatus. A metal beam, half-kilogram slotted weights, a metre scale, slide callipers (or screw gauge), travelling microscope (or cathetometer), spirit-level and a thermometer.

Description of the apparatus. A metal beam (bar) AB of about a metre long and of uniform rectaugular cross-sction, is placed horizontally on two knife-edges K_1 and K_2 fixed on two vertical stands having levelling screws at their bases (not shown in the figure). At the middle of the bar, there is a frame R which carries a knife-edge K whose sharp edge is placed on the bar. At the top of the frame there is a sharp pointer P while the bottom carries a hook from which a hanger H is suspended. Various loads can be put on this hanger to depress the middle point of the bar.



(Fig. 1.20)

Theory. If a beam of breadth b and depth d is placed horizontally on two knife-edges at a distance L apart, then the depression l of the middle point of the bar caused by a load of M gm is given by

$$l=\frac{MgL^3}{4bd^3Y} \quad \cdots \quad (1).$$

Hence Young's modulus of the material of the beam

$$Y=\frac{gL^3}{4bd^3}\left(\frac{M}{l}\right) \quad \cdots \quad (2).$$

Procedure. (i) Make a transverse mark just at the middle of the bar by a pencil and also make three pairs of marks (C, C_1; D, D_1; and E, E_1) at equal distances on the opposite sides of the central mark. Usually $CC_1=70$ cm, $DD_1=80$ cm and $EE_1=90$ cm.

(ii) Place the beam on the knife-edges K_1 and K_2 so that K_1 and K_2 are exactly on the two extreme end-marks E and E_1 respectively. Put a spirit-level on the central mark and adjust the levelling screws at the base of the vertical stands of knife-edges K_1 and K_2, till the bubble comes at the centre. The beam is thus made horizontal.

(iii) Place the frame R containing the knife-edge K and the hanger H, on the beam so that sharp edge of K just touches the central transverse mark, while sharp edges of K_1 and K_2 just touch the marks E and E_1 respectively.

(iv) Adjust the levelling screws at the base of the microscope (or of cathetometer) until the vertical scale is perfectly vertical and the axis of the microscope (or of the telescope of the cathetometer) is horizontal. Determine the least constant of the vertical scale of a travelling microscope (or of a cathetometer) and sharply focus its cross-wire. Then place the microscope (or cathetometer) at a suitable distance and focus clearly the sharp edge of the pointer P so that there is no parallax between the images of the horizontal cross-wire and the sharp edge of P.

(v) When the load on the hanger is zero, note the reading (R_0) of the vertical scale and vernier after making the horizontal cross-wire tangential to the tip of P.

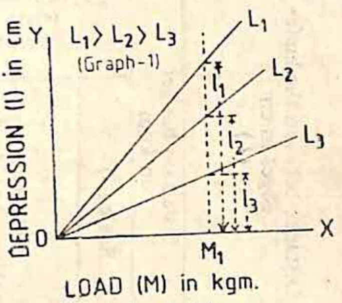
(vi) Repeat the operation (v) by increasing the loads on the hanger by steps of $\frac{1}{2}$ kgm (or 1 kgm) until readings for six or seven such steps are obtained. Decrease the loads on the hanger in the same steps as before and note the readings of the scale and vernier until the load on the hanger is reduced to zero. Substract the mean of the two readings (one for load increasing and another for load decreasing) for zero load on the hanger from that of any other load. This gives the depression for that portical load.

(vii) Now rotate the beam about its axis by 90° so that the former depth now becomes the breadth of the bar. Repeat the operations (v) and (vi) for the same loads as before and then measure the distance EE_1 by a metre scale for three times and find out their mean value.

(viii) Place the knife-edges K_1 and K_2 successively on the marks D, D_1 and C, C_1 and repeat the entire operations ranging from (v) to (vii).

(ix) Measure the breadth and depth of the bar at several places by a slide callipers (or by a screw gauge) along the entire length of the bar and take their mean values after applying correction for zero-error, if any.

(x) Draw graphs on a graph paper by plotting loads M in kgm or gm along x-axis while the depression l in cm along y-axis, taking (0, 0) as origin. The graph will be a straight line passing through the origin. On the same graph paper, draw three such straight lines for three different lengths between the knife-edges (K_1 and K_2) for a particular breadth and depth of the bar. Similarly, draw three straight lines on a second graph paper for three different lengths between K_1 and K_2 when the former breadth is now made the depth.



(Fig. 1.21)

Draw a vertical line on the first graph paper cutting the three lines (fig. 1 21). Find out the coordinates (M, l) of the three points of intersections of this vertical line with the three (load-depression) curves. Then from each graph, find out ML^3/l and put this mean ML^3/l for the three curves in the relation (2) giving Y. In a similar manner find out another value of Y from the curves of second graph paper. Then find out the mean of these two values of Y.

Observations and Calculations

(A) *Load-depression record by microscope* (*or cathetometer when breadth is b and depth is d.*

1 smallest division of the main scale = ...mm = ...cm.

....V. div. = ...M. S. div.

∴ 1 V. div. = ...M. S. div. = ...cm.

∴ Least count = 1 M. S. div. − 1 V. div. = ...cm.

Room temperature = ...°C.

Value of g taken = ... cm/sec^2.

No. of obs.	Distance between the knife-edges in cm (L)	Load on hanger in kgm	Readings in cm when load increasing			Reading in cm when load decreasing			Mean reading in cm $R=(R_1+R_2)/2$	Depression in cm (d)
			Scale (S)	Vernier $V=$(V. read.)×L. C.	Total reading $R_1=S+V$	Scale (s)	Vernier $V=$(V. rea.)×L. C.	Total reading $R_2=S+V$		
1	(i) (…)−(…) =……	0	……	(…)×(…) =……	……	……	(…)×(…) =……	……	…(a)	0
	(ii) (…)−(…) =……	·5	……	(…)×(…) =……	……	……	(…)×(…) =……	……	…(b)	(b)−(a)
	(iii) (…)−(…) =……	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.
	Mean L_1 =……	3	……	(…)×(…) =……	……	……	(…)×(…) =……	……	…(g)	(g)−(a)
2	(i) (…)−(…) =……									
	(ii) (…)−(…) =……									
	(iii) (…)−(…) =……									
	Mean L_2 =……									
3	Mean L_3 =……									

(B) *Load-depression record when breadth is d and depth is b.*

(Make a table similar to the above table.)

(C) *Measurement of breadth (b) and depth (d) of the bar.*

1 M. S. divn. of the slide callipers = ... cm.

. . . . . . vernier divns. coincide with . . . . M. S. divns.

∴ 1 Ve . divn. = ... cm.

∴ Least count of the slide callipers = 1 M. S. − 1 Ver.

= . . . . cm

Zero-error = ± . . . . cm.

No. of obs.	Measurement of	Readings in cm of		Total reading in cm $R=S+V$	Mean reading in cm	Corrected breadth or depth in cm
		Scale (S)	Vernier (V) = V.r.×L. C.			
1	breadth (b)	...	$(\ldots)\times(\ldots)=\ldots\ldots$	....	......	$\ldots=b$
2		...	$(\ldots)\times(\ldots)=\ldots\ldots$	....		
...						
...						
...						
6		...		....		
1	depth (d)	...	$(\ldots)\times(\ldots)=\ldots\ldots$	....	......	$\ldots=d$
2		...	$(\ldots)\times(\ldots)=\ldots\ldots$	....		
...						
...						
...						
6		...	$(\ldots)\times(\ldots)=\ldots\ldots$			

(D) *Calculation of Y from graphs.*

No. of obs.	Graph number	Values of load (M) in gm from graph	Corresponding depression (l) in cm from graph	Corresponding length (L) in cm between two knife-edges	Value of $\frac{ML^3}{l}$	Mean $\frac{ML^3}{l}$	Values of Y in dynes/cm^2	Mean Y in dynes/cm^2
1	I	...	...	...	...	...	$Y=\frac{g}{4bd^3}$	
2	When breadth is b and depth is d	...	...	...	...	...	$\times\frac{ML^3}{l}$	...
3		...	...	...	...	...	$=\ldots$	
1	II	...	...	...	...	...	$Y=\frac{g}{4db^3}$	
2	When breadth is d and depth is b	...	...	...	...	...	$\times\frac{ML^3}{l}$	...
3		...	...	...	...	...	$=\ldots$	

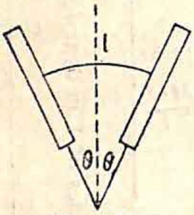
Result. $Y = \ldots\ldots$ dynes/cm^2 $= \ldots\ldots$ Nm^{-2}.

Standard value $= \ldots\ldots$ Nm^{-2}.

Precautions. (i) As the expression for contains the cube of length and depth, they should be measured very carefully, otherwise a large error will occur in the value of Y. (ii) The beam should be made horizontal and the loading should be made just at the middle. (iii) To reduce errors in Y, six values of it should be found out so that the error in Y will be $1/\sqrt{6}$ times the error introduced in one observation. For this sake, three different lengths of the bar should be taken and for each legnths, the depressions should be noted by making the depth as breadth and vice-versa.

EXPERIMENT 12. Determination of Poisson's ratio and elastic constants for the material of a wire by Searle's method.

Apparatus. Searle's apparatus consisting of two identical brass rods connected together at their midpoints by a length of the wire under test, the diameter of the wire should be small compared with its length; screw gauge, slide callipers, stop-watch, cotton-thread.



(Fig. 1.22)

Theory. Consider the state of affairs when each rod is displaced at an angle θ from its equilibrium position. The wire is bent into a circular arc of radius of curvature $l/2\theta$ and the bent wire exerts a restoring torque on each rod equal to the moment of the flextural stresses produced in the wire by the motion of the rod.

For a slightly bent wire this moment $= \dfrac{iY}{R} = \dfrac{\pi a^4 Y}{2l}\theta$, since $i = \pi a^4/4$ is the moment of inertia of cross-section for a wire of circular cross-section, a being the radius of the wire.

The equation of motion of the rod is thus—

$$I\frac{d^2\theta}{dt^2} = -\frac{\pi a^4 Y}{2l}\theta,$$

where I = moment of inertia of the rod.

The motion is thus simple harmonic and the periodic time is

$$T_1 = 2\pi\sqrt{\frac{2Il}{\pi a^4 Y}}$$

from which Young's modulus $Y=\frac{8\pi Il}{T_1^2a^4}$ .. (1).

With one rod clamped in a horizontal position, the periodic time is

$$T_2=2\pi\sqrt{\frac{2Il}{\pi a^4 n}}$$

from which rigidity modulus $n=\frac{8\pi Il}{T_2^2a^4}$ .. (2).

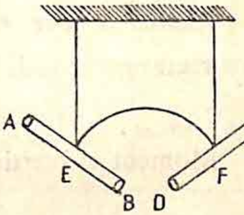
But $1+\sigma=\frac{Y}{2n}$ where $\sigma=$ Poisson's ratio.

$$\therefore \qquad \sigma=\left\{\tfrac{1}{2}\left(\frac{T_2^2}{T_1^2}\right)-1\right\} \quad .. \ (3).$$

Having found Y and n from equations (1) and (2) above, the bulk modulus K can be calculated from the relation

$$\frac{1}{Y}=\frac{1}{aK}+\frac{1}{3n} \quad .. \ (4).$$

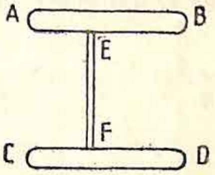
Procedure. (i) First suspend the rods by parallel cotton-threads (preferably silk fibres) of equal length (50 cm) as shown in the fig. 1.23 so that the rods and the wire are in the same horizontal plane. Put a vertical chalk mark on end face of either rod.



(Fig. 1.23)

(ii) Draw together slighty the ends B and D of the rods by a loop of cotton thread. Burn the cotton and take the time of 50 torsional oscillations by a stop-watch with reference to the chalk mark. Repeat this process three times and find out the mean time for fifty oscillations from which calculate the mean time period T_1.

(iii) Now clamp the rod AB in a firm support and allow the lower rod CD to execute torsional oscillations round the axis of the wire. Obtain the periodic time T_2 by timing 50 of these oscillations as described before.



(Fig. 1.24)

(iv) Measure the length (l) of the wire several times by a metre scale and find out its mean.

(v) Find the radius (a) of the wire from at least six readings of the diameter taken by a screw gauge at different points along the wire.

(vi) Weigh each rod. Also measure their lengths by a metre scale and their radii by a slide callipers. For rods of rectangular cross-section, measure their breadths by the slide callipers.

Observations and Calculations

(A) *To find the moment of inertia of the rods.*

Mass of the rod $AB = \ldots.\text{gm} = M_1$.

Mass of the rod $CD = \ldots.\text{gm} = M_2$.

Length of the rod $AB = \ldots.\text{cm} = L_1$.

Length of the rod $CD = \ldots.\text{cm} = L_2$.

Least count of slide callipers $= \ldots.\text{cm}$

zero-error $= \pm \ldots.\text{cm}$.

∴ Radius of the rod $AB = \ldots.\text{cm} = r_1$,

Radius of the rod $CD = \ldots.\text{cm} = r_2$.

[For rectangular rod, breadth of the rod $AB = \ldots.\text{cm} = b_1$,

breadth of the rod $CD = \ldots.\text{cm} = b_2$.]

∴ Moment of inertia of the rod AB

$$= I_1 = M_1\left(\frac{L_1^2}{12} + \frac{r_1^2}{4}\right) = \ldots.\text{gm cm}^2.$$

Moment of inertia of the rod CD

$$= I_2 = M_2\left(\frac{L_2^2}{12} + \frac{r_2^2}{4}\right) = \ldots.\text{gm cm}^2.$$

[For rectangular rod, $I_1 = M_1\left(\frac{L_1^2 + b_1^2}{12}\right)$

and $$I_2 = M_2\left(\frac{L_2^2 + b_2^2}{12}\right).]$$

∴ Mean $I = \frac{I_1 + I_2}{2} = \ldots\ldots.\text{gm cm}^2$.

(**B**) *To find the length and radius of the wire.*

Length of the wire, l = (i) ....cm
(ii) ....cm } Mean = ...cm.
(iii) ....cm

Pitch of the screw gauge = ...cm,

No. of circular scale divns. = ...

Least count of the screw gauge = ...cm,

Zero-error = ± ....cm.

No. of obs.		No. of complete rotn.	Compt. rotn. × pitch (cm)	cap. reading	corrected cap. reading	Total (cm)	Mean diameter (cm)	Mean radius r (cm)
1.	D	....	....	......	....	...		
	C	... .	....	......	....	...		
2.	D	....	....	......	....	...	......	....
	C	....	....	......	....	...		
3.	D	....	....	......	....	...		
	C	....	....	......	....	...		

(**C**) *To find T_1 and T_2.*

No. of obs.	No. of complete oscillations	When both the rods are oscillating			When rod *CD* is oscillating		
		Time taken (sec)	Mean time (sec)	Time period T_1 (sec)	Time taken (sec)	Mean time (sec)	Time period T_2 (sec)
1	50	......			......		
2	50	......			......		
...			....	....		....	....
...							
5	50	......					

If now a body of regular shape be placed symmetrically on the table (disc) such that its centre of gravity is vertically above the centre of gravity of the table, then the suspension axis of the latter passes through the c.g. of the combined system. The time period of oscillation of the combined system about the suspension axis is given by

$$T_1 = 2\pi\sqrt{\frac{I_0 + I_1}{c}} \quad .. \quad (2),$$

where I_1 is the moment of inertia of the regular body about the suspension axis and its value can be calculated.

Finally, if the experimental body be kept on the table (disc) in place of regular body such that its centre of gravity is vertically above that of the table, then the suspension axis of the latter again passes through the c.g. of the new combined system. The time period of oscillation of the new combined system about the suspension axis is then given by

$$T_2 = 2\pi\sqrt{\frac{I_0 + I_2}{c}} \quad .. \quad (3),$$

where I_2 is the moment of inertia of the experimental body about an axis passing through its centre of gravity.

From these three equations, eliminating I_0 and c, we get

$$I_2 = \frac{T_2^2 - T_0^2}{T_1^2 - T_0^2} . I_1 \quad .. \quad (4).$$

Procedure. (i) Level the base by means of a spirit-level and levelling screws L_1, L_2, L_3.

(ii) Adjust the position of masses within the groove till the disc is horizontal, as indicated by the spirit-level. In this condition suspension axis is perpendicular to the plane of disc and passing through its centre of gravity.

(iii) Put a chalk mark on the vertical edge of the disc to note its oscillations. Now rotate the disc in a horizontal plane through a small angle and release it. The disc begins to oscillate due to torsion in the suspension wire. Note down the time for 30 complete oscillations by means of a stop-watch and repeat it thrice. Find out the mean time period T_0. There should not be any pendular oscillations of the disc. If there is any, this should be damped out by lightly touching the suspension wire near the lower end.

(iv) Place the regularly shaped body on the disc. If it is a cylinder, place it one of its flat faces. Adjust the position of the body till the disc is again horizontal. Then the centre of gravity of the body is vertically above that of the table and is on the suspension axis.

Note down the time for 30 complete oscillations thrice and find out the mean time period T_1.

(v) Remove the regularly shaped body from the disc and place the experimental body on it, with the axis about which its moment of inertia is to be determined parallel to the suspension axis of the table. Now adjust the position of the body till the disc is again horizontal. Then the two axes coincide. Also the centre of gravity is vertically above that of the table and is on the suspension axis, because the axis about which the moment of inertia of the body is to be determined passes through its centre of gravity.

Note down the time for 30 complete oscillations thrice and find out the mean time period T_2

(vi) Weigh the regularly shaped body by a balance. If the body is a cylinder, measure its diameter and length by slide callipers. (But if the body is a ring, measure its inner and outer radii by slide callipers.)

Using appropriate formula find its moment of inertia I_1.

(vii) Finally, using eqn. (4) calculate the moment of inertia I_2 of the experimental body.

Observations and Calculations

Enter thus—

(**A**) *Reading for the diameter of the cylinder** (the given body of regular shape).

Least count of the slide callipers = ...cm.

Zero-error = ± ....cm.

---

* If it is a ring, then there will be readings for (A) external diameter, (B) internal diameter and (C) mass of the ring.

The moment of inertia of the ring about an axis passing through its c.g. and perpendicular to its plane is given by $I_1 = M\left(\frac{R^2+r^2}{r}\right)$, where M is the mass of the ring and R and r are its external and internal radii respectively.

1. $\begin{cases} D & \ldots\text{cm.} \\ C & \ldots\text{cm.} \end{cases}$ 2. $\begin{cases} D & \ldots\text{cm.} \\ C & \ldots\text{cm.} \end{cases}$ 3. $\begin{cases} D & \ldots\text{cm.} \\ C & \ldots\text{cm.} \end{cases}$

Mean diameter of the cylinder = ...cm.

∴ Mean radius of the cylinder, R = ...cm.

(B) *Mass of the cylinder,* M = ...gm.

∴ Moment of inertia of cylinder about its axis

$$I_1 = \frac{MR^2}{2} = \ldots\ldots\text{gm.-cm}^2.$$

(C) *Readings for the time periods.*

Nature of oscillating body	Time for 30 oscillations in sec	Mean in sec	Time period in sec
Moment of inertia table	(i) ...... (ii) ...... (iii)	...	... (T_0)
Table and regular body	(i) ...... (ii) ...... (iii)	...	... (T_1)
Table and experimental body	(i) ...... (ii) ...... (iii)	...	... (T_2)

∴ Moment of inertia of the experimental body

$$I_2 = \frac{T_2^2 - T_0^2}{T_1^2 - T_0^2} . I_1 = \ldots\ldots\text{gm.-cm.}^2$$

Result. M.I. of experimental body = ...gm.-cm².

Precautions. (i) The disc should be always horizontal. (ii) There should not be any pendular oscillations of the disc.

EXPERIMENT 14. Determination of the moment of inertia of a flywheel about its own axis of rotation.

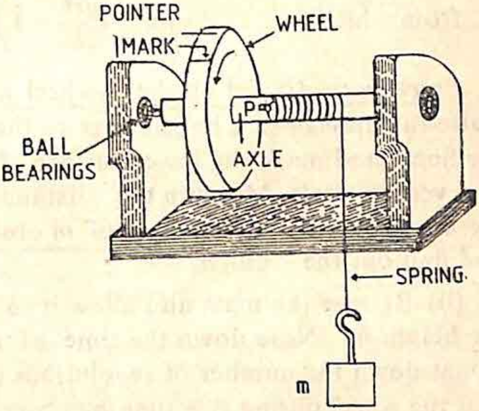
Apparatus. A flywheel, suitable weight, fine cord, stop-watch, metre scale, slide callipers, weight-box and a balance.

Description of the apparatus. FLYWHEEL. It is simply a heavy disc of large diameter to which is attached a long axle of small diameter. It is mounted on ball bearings with its axle horizontal and at a suitable height from the floor. There is a peg P or hole on the axle. A suitable mass m is attached to one end of a fine cord and at the other end is made a large loop which is slipped over the straight peg or pin fitted in the hole. The wheel is rotated so that the cord is wound over the axle uniformly without overlapping. The length of the cord is adjusted so that when the descending mass reaches the floor, the cord detaches itself from the peg or pin. In order to count the number of rotations of the wheel, a reference mark is made on the rim of the wheel opposite to the horizontal pointer fixed to the structure on which the flywheel is mounted.

Theory. Let the mass of the suspended weight be m, and let the moment of inertia of the flywheel be I and the radius of the axle r. Then when the mass descends a distance h it loses potenital energy $=mgh$, and during the same time it acquires kinetic energy $=\frac{1}{2}mv^2$ due to its velocity v at the floor (obstacle), and the wheel acquires kinetic energy $=\frac{1}{2}I\omega^2$ (where $v=r\omega$). Then by the principle of conservation of energy.

$$mgh=\tfrac{1}{2}mv^2+\tfrac{1}{2}I\omega^2+$$

the work done against friction. Let the opposing frictional couple be F, and if the wheel makes n revolutions whilst m falls through h then



(Fig. 1.26)

$$mgh=\tfrac{1}{2}mv^2+\tfrac{1}{2}I\omega^2-F^2\pi n \quad .. \quad (1)$$

Suppose that after the mass is released at the floor (or obstacle) the wheel makes further N revolutions before being brought to rest. The work done against friction during these N revolutions is equal to the kinetic energy of the wheel when m is at the floor—

$$2\pi NF=\tfrac{1}{2}I\omega^2 \quad .. \quad (2).$$

Substituting for F in (1) from (2) we get

$$mgh=\tfrac{1}{2}mv^2+\tfrac{1}{2}I\omega^2+\tfrac{1}{2}I\omega^2\frac{n}{N}$$

$$=\tfrac{1}{2}mv^2+\tfrac{1}{2}I\frac{v^2}{r^2}+\tfrac{1}{2}I\frac{v^2}{r^2}\frac{n}{N}$$

$$=\frac{v^2}{2}\left\{m+\frac{I}{r^2}\left(1+\frac{n}{N}\right)\right\}.$$

Now since the acceleration is constant, the velocity of m at the floor is twice the average velocity during the fall through h, i.e.,

$$v=2h/t.$$

$$\therefore \qquad mgh=\frac{4h^2}{2t^2}\left\{m+\frac{I}{r^2}\left(1+\frac{n}{N}\right)\right\}$$

from which

$$I=mr^2\left(\frac{gt^2}{2h}-1\right)\left(\frac{N}{N-n}\right) \qquad .. \quad (3).$$

Procedure. (i) Set up the flywheel as described in the fig. 1.26. Raise the mass m to a height near to the axle (about 150 cm above the floor) and mark the lower surface of the mass by a pointer fixed to a vertical scale. Measure the distance between the pointer and the floor (or the upper surface of m obstacle) thrice by a metre scale and find out the mean h.

(ii) Release the mass and allow it to fall under gravity through the height h. Note down the time of descent t by a stop-watch. Count down the number of revolutions (both integral and fractional) n of the wheel during this time by observing a mark made on the circumference of the wheel. Also count down the further revolutions N made by the wheel before coming to rest after m is detached by reference to the mark.

(iii) Repeat the operation (ii) thrice for the same height h and take the average values of n, t and N.

(iv) Weigh the mass and obtain the value of m.

(v) Measure the diameter of the axle by a slide callipers at different places along the axle in two perpendicular directions at each place. Find out the mean diameter from which the mean radius of the wheel r is known.

(vi) Now calculate the moment of inertia I of the flywheel.

Observations and Calculations

Mass, $m=$ .... gm.
Height, $h=$ (i) ...... cm, (ii) ...... cm, (iii) ...... cm.
Mean $h=$ ...... cm.

(A) *Measurment of radius of the axle by a slide callipers.*

Least count = ... cm; zero-error = ...cm.

No. of obs.		M.S. (cm)	Vernier reading	Ver. read. × L.C. (cm)	Total = diameter (cm)	Mean diam. (cm)	Corrected diameter (cm)	Mean radius r (cm)
1.	D	...	...	...	...			
	C	...	...	...	...			
2.	D	...	...	...	...	...	...	...
	C	...	...	...	...			
3.	D	...	...	...	...			
	C	...	...	...	...			

(B) *To find t, n and N.*

$t=$ (i) ...... sec, (ii) ...... sec, (iii) ...... sec.

Mean $t=$ .... sec.

	No. of obs.	Integral	Fractional	Total (rev.)
n	1	...	...	...
	2	...	...	
	3	...	...	$(=n)$
N	1	...	...	...
	2	...	...	
	3	...	...	$(=N)$

$$\therefore \quad I=mr^2\left(\frac{gt^2}{2h}-1\right)\left(\frac{N}{N+n}\right)=\ldots\ldots\text{gm-cm}^2.$$

$$=\ldots\ldots\text{kgm-m}^2.$$

Result. $I=$ ....kgm-m^2.

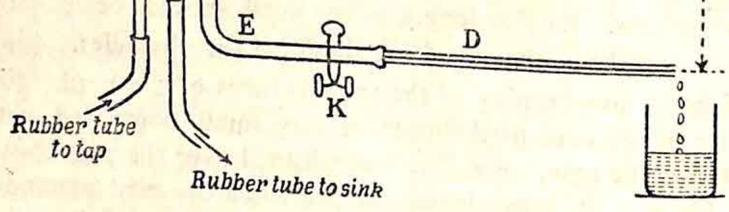
Precautions. (i) The length of the cord should be slightly less than the height of the axle from the floor (or obstacle). (ii) There should be no overlapping of the various turns of the cord. (iii) The diameter of the cord used should be very small compared with the diameter of the axle. (iv) The loop slipped over the peg should be loose so that it must leave the peg when the cord unwind itself. (v) The radius of the axle should be measured carefully. (vi) The mass attached to the cord should be of such a value as to start the motion of the wheel without any external help and sufficient to overcome the bearing friction. (vii) The stop-watch should be started immediately the mass begins to descend.

VISCOSITY

EXPERIMENT 15. Determination of the coefficient of viscosity of liquid (water) by the "rate of flow" method throught a capillary tube

Apparatus. Constant head apparatus, capillary tube, stop-watch, rubber tubings, travelling microscope, balance weight-box, beaker, crucible, a sensitive thermometer, mercury, metre scale, stand and clamp, and a pinch-cock.

Description of the apparatus. CONSTANT HEAD APPARATUS. It consists of a tank (vessel) T provided with an inflow tube A, constant level overflow tube B and outflow tube C. The inflow tube is bent to the horizontal side inside the tank to reduce the risk of shooting water right out of the apparatus when it is turned on too rapidly, and to reduce the likelihood of a small wave (or pile) of water forming vertically over the inflow tube. The ends of the tube are corrugated for rubber tubing connections. The height of the tank from the capillary tube can be varied by sliding it along the supporting rod and can be clamped in any desired position. The end of the outflow tube can be connected to the capillary tube by rubber tubing. The water head in T can be maintained at a constant level corresponding to the uppermost point of B.



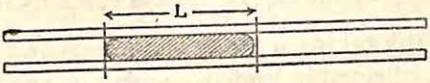
(Fig. 1.27)

Theory. When liquid flows through a capillary tube, as shown in fig. 1.27, the following relationship holds :

$$\eta = \frac{A^2}{8\pi lV}.P = \frac{\pi r^4}{8lV}.h\rho g,$$

where η = the coefficient of viscosity, in gm/cm sec. (called the poise),
P = the pressure difference under which the liquid flows, in dynes/cm^2,
l = length of the capillary tube, in cm,
A = area of the cross-section of the bore of the capillary tube, in cm^2,
V = volume of the liquid (in cc) that flows out in one sec,
r = radius of the bore of the capillary tube, in cm,
h = height of the liquid (water) head above capillary tube, in cm,
ρ = density of liquid, in gm/cm^3,
g = acceleration due to gravity, in cm/sec^2.

Procedure. (i) Take a capillary tube about 50 cm long with a uniform bore about 1 mm in diameter. Wash the bore of the tube first with dil. caustic soda, then with dil. nitric acid and finally in a stream of water. Dry it by passing hot air in it.* Attach a rubber tubing to one end and dip the other end of it into clean and dry mercury. Close the free-end of the rubber tube by *pinch-cock* and then press the rubber tube in the middle. Release the pressure. A mercury pellet will be drawn in. Closing the end of the cap. tube under mercury with a finger, take out the tube from the mercury and place the tube flat on a horizontal base. Measure the length of the mercury pellet with a travelling microscope at different parts of the tube. Find out the length L in cm. Weigh an empty clean crucible. Empty the mercury into the crucible and reweigh it. The difference will give the mass of the mercury M, in gm. Determine the value of r^2



(Fig. 1.28)

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* The diameter (hence) of the bore can also be measured (whenever a greater accuracy is not required) by a travelling microscope. Measure the diameter at both ends of the tube and take both direct and cross readings at each end. The mean will give the diameter.

(whence r^4) from the relation, $M = \pi r^2 L\, d$, where d is the density of mercury at that *temperature*.

(ii) After removing the rubber tube, measure the length of the cap. tube by a metre scale to the nearest mm. Repeat it thrice and find the mean length l cm.

(iii) Now connect the cap. tube to outflow tube B by rubber tubing E. Keep the tube horizontal on its base, testing this by a spirit level. Allow the water to flow through the tube which is possible when the supply of water through A is slightly in excess of that flowing out through the cap. tube and this excess water flow out through the tube B. Adjust the height of the tank T *till the emergent water issues as a slow trickle or succession of drops*, so that the kinetic energy of the water is small. A pinch-cock K is used so that the flow of water can be started or stopped at will.

(iv) When the flow of water in the tube has become steady, collect the water trickling from the end of the tube in a previously weighed beaker for a known interval of time (determined by a stop-watch). Weigh the beaker with its contents again. 100 to 150 gm of water should be collected. Repeat the collection of water thrice for the same interval of time. Find the volume of water by dividing the mass of water collected by the density of water at that temperature. From this calculate V, the volume of water flowing per sec through the cap. tube. Carefully record the temperature of water in the tank by a sensitive thermometer.

(v) Now measure the height (h cm) of the water-head above the cap. tube* by a metre scale to the nearest mm.

(vi) Repeat the experiment for different height of water, taking care that the motion of the liquid always remains in streamlines.

(vii) Plot a graph taking h along the x-axis and the corresponding mass m of water collected in known time along the y-axis (Fig. 1.29). The graph should be linear. For large values of h the departure from the straight line in the graph indicates the presence of turbulent motion in the tube. From the linear part of the graph obtain the value of h and m and then calculate η.

---

* Measure the height of the water head in T and the height of the axis of the cap. tube from the table. The difference will give the required height.

Observations and Calculations

Enter thus—

(A) *Readings for the radius of the bore.*

1 main scale divn. of the travelling microscope = 0·05 cm.

50 vernier divisions coincide with 49 main scale divns.

$\therefore$ 1 ver. divn. = $\frac{49}{50} \times 0{\cdot}05$ cm.

$\therefore$ Least count of the microscope = 0·001 cm.

Length of the mercury pellet—

(i)........cm, (ii)........cm, (iii)........cm.

Mean, $L = 16{\cdot}159$ cm.

Weight of the empty crucible = ...gm.

Weight of crucible + mercury = ...gm.

$\therefore$ Mass of mercury, $M = 3{\cdot}026$ gm.

Temperature of mercury = 31·4°C.

$\therefore$ Density of mercury at 31·4°C, $d = 13{\cdot}52$ gm/cc.

$$\therefore \quad r^2 = \frac{M}{\pi L d} = \frac{3{\cdot}026}{3{\cdot}1416 \times 16{\cdot}159 \times 13{\cdot}52} \text{ sq. cm.}$$

$\therefore \quad r^4 = 1{\cdot}942 \times 10^{-5}$ cm^4.

(B) *Length of the Capillary tube.*

(i) .... cm, (ii) .... cm, (iii) .... cm.

Mean, $l = 77{\cdot}85$ cm.

(C) *Weight of the empty beaker*, $m_1 = 62{\cdot}705$ gm.

(D) *Temperature of Water.*

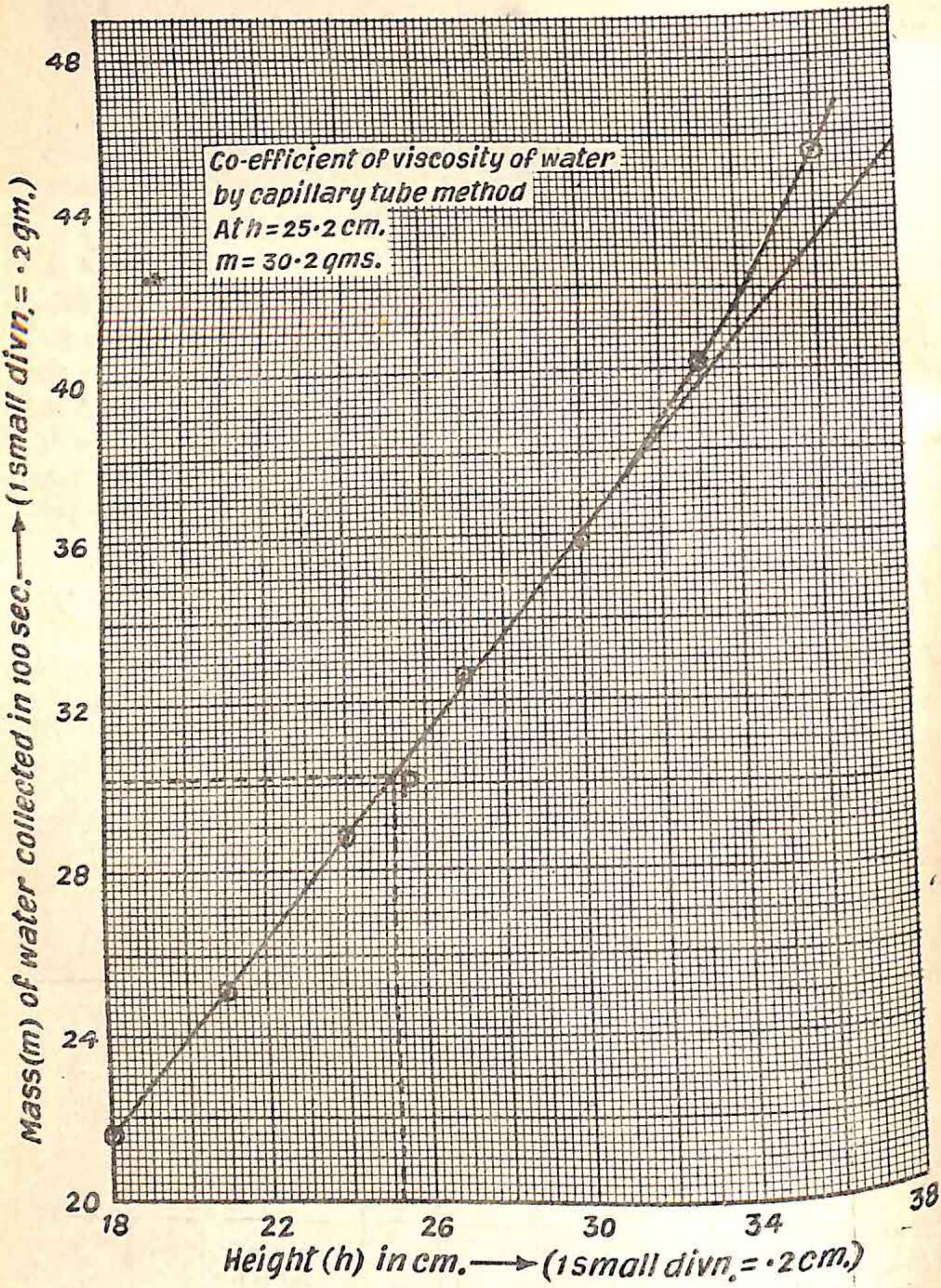
(i) .... °C, (ii) .... °C, (iii) .... °C.

Mean temp. = 31·4°C.

Density of water at 31·4°C, $\rho = 0{\cdot}9957$ gm/cm^2.

(E) *Readings for height h versus V.*

No. of obs.	Height of the water-head above the cap. tube, h, in cm	Weight of the beaker + water in gm				Mass of water collected, $m = m_2 - m_1$, in gm	Time taken t in sec	Volume of water flowing per sec, $V = \frac{m}{\rho . t}$ in cc/sec	$\frac{h}{V}$	Mean $\frac{h}{V}$	η in poise
		I	II	III	Mean $= m_2$						
1	18	...	...	...	84·239	21·534	100	0·21627	83·23	82·31	0·00787 (at 31·4°C)
2	21	...	...	...	87·818	25·113		0·25221	83·26		
3	24	...	...	...	91·410	28·705		0·28828	83·25		
4	27	...	...	...	95·306	32·601		0·32745	82 45		
5	30	...	...	...	98·508	35·803		0·35956	83·43		
6	33	...	...	...	102·807	40·102		0·40274	81·94		
7	36	...	...	...	108·281	45·576		0·45773	78·65		



(Fig. 1.29)

From graph (fig. 1.29),

At $h = 25{\cdot}2$ cm, the mass of water collected in 100 sec. $= m$ $= 30{\cdot}2$ gm.

$$\therefore \quad V=\frac{30{\cdot}2}{0{\cdot}9957\times 100} \text{ cc/sec.}$$

$\therefore$ The coefficient of viscosity of water at 31·4°C,

$$\eta=\frac{3{\cdot}1416\times 1{\cdot}94\times 10^{-5}\times 25{\cdot}2\times 0{\cdot}9957\times 980\times 0{\cdot}9957\times 100}{1\times 77{\cdot}85\times 30{\cdot}2}$$

$=0{\cdot}00794$ poise.

Result. The coefficient of viscosity of water at 31·4°C

$=0{\cdot}00787$ poise (from calculations)

$=0{\cdot}00794$ poise (from graph).

Standard value at that temperature= . . . . .poise.

Precautions. (i) The bore of the capillary tube should not be more than 1 mm in diameter, otherwise the motion of the liquid will not be streamline. With wider tubes the velocity of the liquid exceeds the critical velocity and becomes turbulent. (ii) The capillary tube chosen for the experiment should have a uniform bore. By measuring the diameter at both ends with a travelling microscope, the uniformity of the bore should be tested. (iii) The cap. tube should be placed horizontally. (iv) The rate of flow of water should be so adjusted (by increasing or decreasing the height of the water-head above the cap. tube) that it trickles down slowly. If before trickling, the water runs back along the side of the cap. tube, apply a little grease (or soft wax) at the end of the tube. But take care that no grease gets into the bore of the tube. (v) Since the radius of the bore of the tube is to be raised to the fourth power, it should be measured very carefully. (vi) The tap should be turned on for at least five minutes before the inflow tube *A* is connected to the tap, so as to eliminate the temperature fluctuations which occur in water between the deep mains and the taps. (vii) As the viscosity of a liquid depends upon its temperature, the latter should be noted very carefully with a sensitive thermometer and it should be reported with the result. Remember that η decreases with an increase of temperature. (viii) There should be no constriction in the rubber tube *E* connecting the cap. tube and the outflow tube *C*.

Discussion. The apparatus yields a fairly satisfactory result if the rate of flow of water through the capillary tube is kept small. If the error due to kinetic energy of liquid (water) and its acceleration near the entrance end of the cap. tube is to be eliminated, the following relation is to be employed for the determination of η.

$$\eta = -\frac{\pi r^4}{8V(l+1\cdot 64r)}\rho g\left(h - \frac{V^2}{g\pi^2 r^4}\right).$$

But the capillary flow method is not suitable for determining the viscosity of very viscous liquids, such as oils.

ASSOCIATED EXPERIMENT

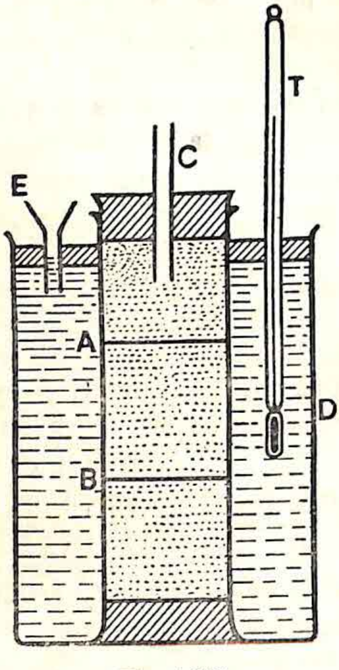
1. *Show the variation of V with h.*

Hint. Plot the $(V-h)$ graph which will indicate the variation of V with h.

EXPERIMENT 16. Determination of the coefficient of viscosity of castor oil by using Stoke's formula.

Apparatus. Steel-balls, screw gauge, stop-watch and Stoke's formula apparatus.

Description of the apparatus: STOKE'S FORMULA APPARATUS. It consists of a tall (nearly one metre long) cylinder BA containing the experimental liquid (castor oil). The two ends of the cylinder are closed by rubber corks. A tube C is introduced in AB through a hole in the upper cork in such a way that axis of the tube coincides with that of the cylinder. The diameter of the tube C is slightly greater than that of the balls to be used so that the ball may easily pass through the tube and fall along the axis of the cylinder. A and B are two marks on the outer wall of the cylinder so that the whole column of liquid in the cylinder is divided into three equal parts. The cylinder is kept vertically within a vessel D containing water so that the variation of temperature of liquid due to transference of heat may be avoided. The thermometer T gives the temperature of water of the



(Fig. 1.30)

vessel and hence of the experimental liquid in the cylinder.

Theory. Stoke showed that if a small sphere of radius r and density ρ assumes a terminal (uniform) velocity in an *infinite extension* of liquid of density σ, viscous drag exerted on the sphere is given by

$$F = 6\pi\eta r v,$$

where η is the coefficient of viscosity of the liquid. When the sphere falling freely from rest under gravity through the liquid, attains the terminal velocity, the apparent weight of the sphere in the liquid $\frac{4}{3}\pi r^3(\rho - \sigma)g$ becomes equal to the viscous drag $6\pi\eta r v$.

$$\therefore \quad \eta = \frac{2}{9}\,\frac{(\rho-\sigma)gr^2}{v} \qquad \text{.. (1).}$$

This is called *Stoke's formula.* (When vr is small compared to η, Stoke's formula holds good.)

Procedure. (i) Measure the diameter of each steel-ball three times, taking both direct and cross readings, each time, by a screw gauge. Then find out the mean radius r, in cm, of each ball.

(ii) Before introducing the balls in the cylinder, wet them thoroughly with the experimental liquid.

(iii) Now, first introduce the ball of lowest diameter in the tube C. The ball will travel downward along the axis of the cylinder and it will assume terminal velocity as it reaches the upper mark A. Measure the time t in sec taken by the ball to travel from marks A to B by a stop-watch.

(iv) Repeat the operation (iii) with balls of increasing diameter. Measure the distance between the marks A and B thrice by a metre scale and find out the mean distance s in cm. Now, find out the terminal velocity v for each ball by dividing s by corresponding time t.

(v) Note down the densities ρ and σ of the balls and the experimental liquid respectively from a book of constants or determine them by means of a specific gravity bottle.

(vi) Note down the temperature of the experimental liquid by the thermometer T.

(vii) Plot a graph taking r^2 in sq. cm along x-axis and $1/t$ in sec^{-1} along y-axis (fig. 1.31). The graph will be a straight line passing through the origin. Take a point on this straight line graph and find out the value of r^2 and corresponding $1/t$. Calculate η from this.

Obsesvations and Calculations

Enter thus—

(A) *Readings and radii of balls.*

Pitch of the screw gauge = 0·05 cm.

Least count $= \frac{0{\cdot}05}{50} = 0{\cdot}001$ cm.

Zero-error = nil.

Ball no.	No. of obs.	No. of complete rotations	Cap. div.	Diam. in cm	Mean diam. in cm	Mean radius r in cm
1	1 D	4	13	0·213	0·213	0·1065
	C	4	13	0·213		
	2					
	3					
2	1 D	5	29	0·279	0·2792	0·1396
	C	5	29·5	0·2795		
	2					
	3					
3	1 D	6	10	0·310	0·3105	0·1552
	C	6	11	0·311		
	2					
	3					
4	1 D	6	39	0·339	0·338	0·1690
	C	6	37	0·337		
	2					
	3					
5	1 D	7	23	0·373	0·373	0·1865
	C	7	23	0·373		
	2					
	3					
6	1 D	7	45	0·395	0·395	0·1975
	C	7	45	0·395		
	2					
	3					
7	1 D	8	21	0·421	0·422	0·2110
	C	8	23	0·423		
	2					
	3					

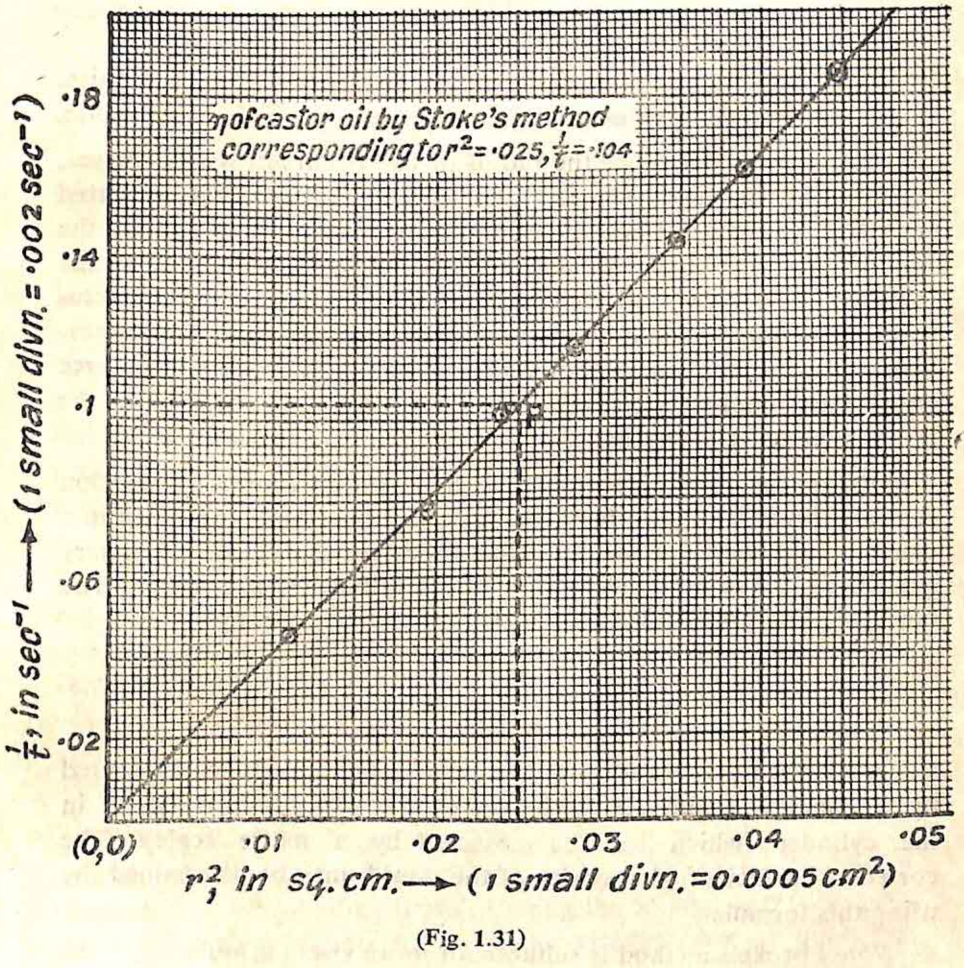
(B) *Distance between two marks.*

(i) ....cm, (ii) ....cm, (iii) ....cm.

∴ Mean distance $s = 58{\cdot}3$ cm.

(C) *Readings for terminal velocity.*

Ball no.	r^2 in cm	Time of fall t in sec	$\frac{1}{t}$ in sec^{-1}	Terminal velocity $v=s/t$ in cm/sec.
1	·01134	21·74	0·04599	2·68
2	·01949	12·8	0·07813	4·55
3	·02408	9·9	0·101	5·88
4	·02856	8·5	0·176	6·85
5	·03475	6·9	0·1439	8·38
6	·03901	6·25	0·1613	9·40
7	·04452	5·4	0·1852	10·79



(Fig. 1.31)

(D) Temperature of experimental liquid $=30°C$.

(E) Density of balls, $\rho=7{\cdot}72$ gm/cc.

Density of exptal. liquid (castor oil), $\sigma=0.96$ gm/cc.

From graph (fig. 1.31),

$$\frac{1}{t}=0{\cdot}104 \text{ sec.}^{-1} \text{ for } r^2=0{\cdot}025 \text{ sq./cm.}$$

$$\therefore \quad t=9{\cdot}615 \text{ sec.}$$

$$\therefore \quad \eta=\frac{2}{9}\frac{(\rho-\sigma)gr^2}{v}=\frac{2}{9}\frac{(\rho-\sigma)gr^2}{s/t}$$

$$=\frac{2\times(7{\cdot}72-0{\cdot}96)\times980\times0{\cdot}025\times9{\cdot}615}{9\times58{\cdot}3}$$

$$=6{\cdot}067 \text{ gm per cm per sec. (poise).}$$

Result. Coefficient of viscosity of castor oil at 30°C = 6·067 poise.
Standard value at that temperature = ... poise.

Precautions. (i) Since the radius of ball occurs in second power, it should be measured very carefully. (ii) That balls should be wetted with the experimental liquid before they are allowed to fall in the liquid. (iii) The balls should be allowed to fall axially down the cylinder. (iv) As viscosity changes rapidly with temp., the temperature of the liquid should be maintained constant during the experiment. (v) The two marks should divide the liquid column into three equal parts and the central part should be used to determine the terminal velocity of the balls.

Discussion. Stoke's formula has been proved on the assumption that the liquid is of infinite extension. But the liquid contained in a cylinder is of finite extension. Hence a correction due to boundary conditions at the wall and bottom of the cylinder is necessary. The corrected Stoke's formula (due to Ladenburg) is given by

$$\eta=\frac{2}{9}\frac{(\rho-\sigma)gr^2}{v\left(1+2{\cdot}4\frac{r}{R}\right)\left(1+3{\cdot}3\frac{r}{h}\right)},$$

where R is the internal radius of the cylinder (which can be measured by slide callipers) and h is the height of the experimental liquid in the cylinder (which can be measured by a metre scale). The corrected coefficient of viscosity of the liquid may be determined by using this formula.

Note : Stoke's method is suitable for more viscous liquid.

ASSOCIATED EXPERIMENT

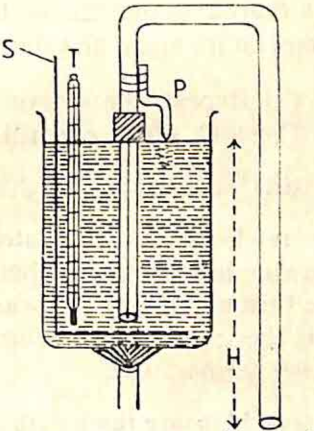
1. *Verify Stoke's formula*

Hint. Perform expt. 16 and plot $\left(r^2-\frac{1}{t}\right)$ or (r^2-v) graph. If the graph is a straight line passing through the origin then Stoke's law will be verified.

EXPERIMENT 17. Determination of the coefficient of viscosity of a liquid at different temperatures.

Apparatus. Reynold's apparatus, a tall beaker of one litre capacity, beaker, stop-watch, metre scale, travelling microscope, mercury, watch glass, weight-box and balance.

Description of the apparatus : REYNOLD'S APPARATUS. It consists of a siphon of glass tube (short tube about 10 cm long and long tube about 60 cm long and both about 5 mm bore) connected to a length of capillary tube (about 15 cm long and 0·5 mm bore) by means of a short length of rubber tubing. A pin, P, bent twice at right angles, is attached to the tube by means of two rubber bands. The liquid is placed in a tall beaker (one litre capacity) and the point of the pin is adjusted to coincide with the surface. A stirrer S and a thermometer T are provided inside the liquid. There is a heating arrangement to raise the temperature of the liquid.



(Fig. 1.32)

Theory. The total volume of liquid (coefficient of viscosity η) passing through the capillary tube (length l and internal radius r), per second V is given by

$$V=\frac{\pi r^4 P}{8l\eta}.$$

The presssuse P has the value ρgH, if it is remembered that the column of liquid in the capillary tube is supported by the upthrust of the surrounding liquid, leaving the column ρgH to provide the pressure necessary to overcome the viscous forces. Hence the coefficient of viscosity of liquid at the temperature

$$\eta=\frac{\pi r^4 \rho g H}{8lV},$$

where ρ is the density of liquid at θ°C.

If m be mass of the liquid collected in t sec,

then $$V=m/\rho t.$$

$$\therefore \quad \eta=\frac{\pi r^4 \rho^2 g H t}{8lm} \text{ poise at } \theta°\text{C}. \qquad .. \quad (1).$$

Procedure. (i) Set up the apparatus as shown in the fig. 1.32. Fill the tall beaker with liguid up to level shown. Heat the liquid and raise its temperature to about 70°C. Stir the liquid and note the temperature by the thermometer. Suck over the liquid and collect the liquid in a weighed beaker for a given time t (say 2-3 minutes) as recorded by a stop-watch. Weigh the beaker with the collected liquid and find out the mass m of the collected liquid. As liquid flows out, the level of the liquid in the tall beaker falls and beaker is raised or tube is lowered so that the point of the pin P always coincide with the surface of the liquid. Note the temperature again and find the mean temperature (θ°C).

(ii) Repeat the above procedure at intervals of 10°C, i.e., at 60°C, 50°C, 40°C, etc. till the room temperature is reached.

(iii) Measure the height H by a metre scale.

(iv) Find out the internal radius (r) of the capillary tube by drawing in a mercury pellet as described in Expt. 15 by employing the formula $M=\pi r^2 Ld$, where m is the mass of the mercury pellet, L is the length of the pellet and d is the density of the mercury at room temperature.

(v) Measure the length of the capillary tube thrice by metre scale and find out the mean value of l.

(vi) Note down the density ρ of the liquid at all temperatures of the experiment from a constant table.

(vii) Calculate η at all temperatures using Eqn. (1).

(viii) Draw a graph taking temperature in °C along x-axis and η in poise along y-axis.

Observations and Calculations

(A) *Length of the capillary tube.* (i) ......cm, (ii)......cm,
(iii) ......cm.
Mean $l = \ldots\ldots$cm.

(B) *Radius of the capillary tube.*

Least count of the travelling microscope = ...cm

No. of obs.	Reading of left end of mercury pellet			Reading of right end of mercury pellet			Difference $= \sim b = L$ (cm)	Mean L (cm)
	M.S. (cm)	Ver. read. × L.C. (cm)	Total $= a$ (cm)	S.M. (cm)	Ver. read. × L.C. (cm)	Total $= b$ (cm)		
1	...	......	......	...	......	......	...	
2	...	......	......	...	......	......	...	...
3	...	......	......	...	......	......	...	

Mass of mercury pellet, $M = \ldots\ldots$gm.
Density of mercury at room temperature, $d = \ldots\ldots$gm/cm³.

$$\therefore \quad r^4 = \frac{M^2}{\pi^2 L^2 d^2} = \ldots\ldots \text{cm}^4.$$

(C) *Height H* (i) ......cm, (ii) ......cm, (iii) ......cm
Mean $H = \ldots\ldots$cm.

(D) *Mass of beaker*, $m_1 = \ldots\ldots$gm.

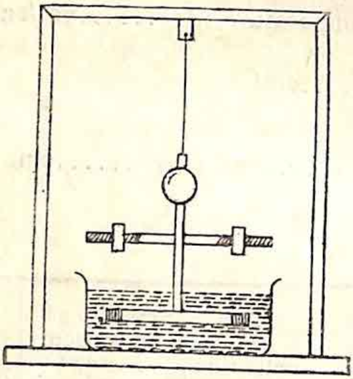
	Temp. of liquid (°C)	Mass of beaker with liquid $= m_2$ (gm)	Mass of liquid collected in t sec $= m = m_2 - m_1$ (gm)	Time of collection t (sec)	Density of liquid from constant table (gm/cm³)	η (poise)
1	$\theta_1 = 70°$	......	......	...	....	...
2	$\theta_2 = 60°$	......	......	...	....	...
3	$\theta_3 = 50°$	......	......	...	....	...
4	$\theta_4 = 40°$	......	......	...	....	...
5	$\theta_5 = 30°$	......	......	...	....	...

Precautions. (i) The radius of the capillary tube should be measured very carefully as it is raised to the fourth power. (ii) The level of the liquid should be always at the pin point. (iii) If the flow of liquid is too rapid, then H must be decreased by raising the siphon provided it is the same at all temperatures. (iv) The liquid should be stirred well before taking reading of the thermometer.

EXPERIMENT 18. Determination of the viscosity of a liquid by the oscillating disc method.

Apparatus. Oscillating disc apparatus, lamp and scale arrangement, screw gauge, metre scale, stop-watch, specific gravity bottle, weight-box, balance, a ring of copper, and thermometer.

Description of the apparatus. OSCILLATING DISC APPARATUS. The flat disc is suspended horizontally by a phosphor-bronze suspension which is attached to a rod rigidly fastened to the centre of the disc. This rod carries a cross-bar whose ends have a screw thread, along which two masses may be screwed to balance the disc horizontally. A small concave mirror is fastened to the rigid support.



(Fig. 1.33)

Theory. The viscosity of a liquid may be determined by timing the period of oscillation of a flat circular disc in air, and finding the logarithmic decrement in the liquid and in air.

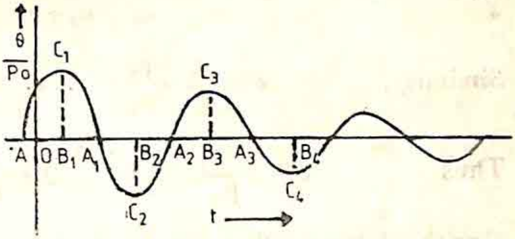
O. E. Nayer has shown that with such a disc, the coefficient of viscosity for a liquid, η, is

$$\eta = \frac{16I^2}{\pi\rho T(r^4+2r^3d)^2} \times \left\{\left(\frac{\lambda-\lambda_0}{\pi}\right)+\left(\frac{\lambda-\lambda_0}{\pi}\right)\right\}^2, \quad .. \; (1)$$

where I is the moment of inertia of the disc and attachments about the axis of suspension, ρ is the density of the liquid, T is the time of complete swing in air, r is the radius of the disc, d is the thickness of the disc, λ is the logarithmic decrement in the liquid, and λ_0 is the logarithmic decrement in air.

The curve of fig. 1.34 is the graph of θ (angular displacement) against t (time) of a damped oscillating disc. Choosing the origin at B_1 we may write

$$\theta = Ce^{-kt/2} \cos \frac{2\pi t.}{T}$$



(Fig. 1.34)

The initial amplitude at $t=0$ is B_1C_1. Half a period later, with $t=T/2$, the displacement is $B_2C_2 = Ce^{-kT/4}$ on the negative side of the axis. A period later, $t=T$, the displacement is $B_3C_3 = Ce^{-kT/2}$, and so on. It is clear that

$$\frac{B_1C_1}{B_2C_2} = \frac{B_2C_2}{B_3C_3} = \ldots = e^{kT/4}.$$

The logarithm of this ratio is denoted by λ. It is called the *logarithmic decrement* and is equal to $kT/4$.

$$\therefore \quad \lambda = 2{\cdot}303 \log_{10} \frac{B_1C_1}{B_2C_2}.$$

The damping is described by means of λ and not by means of k. It is evident that

$$\log_e \frac{B_1C_1}{B_3C_3} = 2\lambda.$$

In general, if observations are made of a maximum displacement and of another, n periods later on the same side, i.e., of the first and $(2n+1)$th maximum displacements, the logarithm of the ratio of the displacements is $2n\lambda$.

If the amplitudes of these displacements be denoted by α_1 and α_{2n+1} respectively,

$$\lambda = \frac{1}{2n} \log_e \frac{\alpha_1}{\alpha_{2n+1}}.$$

Let the successive amplitudes be denoted by α_1, α_2, α_3 etc., α_1, α_3 etc., on one side of the zero; α_2, α_4 etc. on the other side. The full extent of the successive swings from one side to the other will be denoted by β_1, β_2 etc.

Thus $\quad \beta_1 = \alpha_1 + \alpha_2, \quad \beta_2 = \alpha_2 + \alpha_3,$ and so on.

Now $$e^{\lambda}=\frac{\alpha_1}{\alpha_2}=\frac{\alpha_2}{\alpha_3}=\frac{\alpha_1+\alpha_2}{\alpha_2+\alpha_3}=\frac{\beta_1}{\beta_2}.$$

Similarly, $$e^{\lambda}=\frac{\beta_2}{\beta_3}=\frac{\beta_3}{\beta_4}=\ldots\ldots=\frac{\beta_n}{\beta_{n+1}}.$$

Thus $$e^{n\lambda}=\frac{\beta_1}{\beta_{n+1}} \quad \text{or} \quad \lambda=\frac{1}{n}\log_e\frac{\beta_1}{\beta_{n+1}}. \quad \ldots (2).$$

For the determination of λ by the full swing method is to obtain a number of succesive values of full swings, then to wait until the amplitude has died down and to read an equal number of successive values. The time interval must be taken between the first reading of the first sequence and the first reading of the second sequence. Suppose the first set of values are $\beta_1, \beta_2, \ldots\ldots, \beta_{10}$. If the number of half vibrations which occurs between the beginning of each sequence is n, this number can be found from the time interval, t, from the relation $n=2t/T$. Suppose the second set of values are β_{n+1}, β_{n+2}, $\ldots\ldots, \beta_{n+10}$. Then

$$e^{n\lambda}=\frac{\beta_1}{\beta_{n+1}}=\frac{\beta_2}{\beta_{n+2}}=\ldots=\frac{\beta_{10}}{\beta_{n+10}}=\frac{\beta_3+\beta_2+\ldots.+\beta_{10}}{\beta_{n+1}+\beta_{n+2}+\ldots.\beta_{n+10}}$$

or $$\lambda=\frac{1}{n}\log_e\frac{\beta_1+\beta_2+\ldots.+\beta_{10}}{\beta_{n+1}+\beta_{n+2}+\ldots.\beta_{n+10}} \quad \ldots (3).$$

This method has the advantage that, in effect, the average of a number of swings is used and the use of formula (3) ensures that each reading is used once only.

Procedure. (i) Measure the diameter of the disc in different directions by a metre scale and find out the mean radius (r). (ii) Measure the thickness (d) of the disc by screw gauge. (iii) Determine the density of the given liquid using specific gravity bottle.

(iv) Direct a beam of light from a lamp on to the mirror and bring it to focus by the latter on a scale about a metre away. Oscillate the disc in air. As the spot of light passes its rest position on the scale, during its oscillation, start a stop-watch and stop it after fifty complete oscillations. Then find out T, the time for one oscillation (or swing).

(v) Obtain the value of I from the *method of oscillation.* If τ is the restoring couple per unit angular displacement due to the suspension, we have, in air, where the logarithmic decrement is small,

$$T = 2\pi\sqrt{I/\tau} \quad .. \quad (3).$$

Place a small ring of copper on the disc and obtain the time of a complete oscillation (swing) T' from the determination of the time of fifty swings for the loaded disc. Then

$$T' = 2\pi\sqrt{\frac{I+I'}{\tau}} \quad .. \quad (4),$$

where I' is the moment of inertia of the copper wire ring about the axis of suspension.

Measure the radius (a) of the ring of wire by a scale, and also its mass (m) by weighing. Then $I' = ma^2$.

Also $$\frac{T'^2}{T^2} = \frac{I+I'}{I} = 1 + \frac{I'}{I} = 1 + \frac{ma^2}{I}.$$

Hence $$I = \frac{T^2 . ma^2}{T'^2 - T^2} \quad .. \quad (5).$$

Thus calculate the moment of inertia I of the disc and attachments.

(vi) Now find out the logarithmic decrement for the disc oscillating in air; the disc is shielded from thed raught in an empty glass dish. For this, note the position of the light spot at the extreme left from the scale and start the stop-watch simultaneously. Then note the turning point of the light spot when it comes towards right. In this way note ten turning points both towards left as well as towards right. Discontinue the recordings of turning points but allow the stop-watch to run on. When the amplitude of the light spot is reduced to half (or has died down considerably), again start recordings of the turning points when it comes to exterme left and stop the stop-watch simultaneously. Note ten turning points of light spot on the scale at the extreme left and at the extreme right respectively. Note the time interval (t) between the first reading of the first set of swings and the first reading of the second set of swings from the stop-watch. The number of half vibrations is $n = 2t/T$. For example, $n = 2 \times (615/3{\cdot}07) = 400$, if $t = 615$ sec and $T = 3{\cdot}07$ sec.

(vii) Repeat the process (vi) in the liquid whose coefficient of viscosity is to be determined. Water or paraffin oil may be taken as liquid. Record the temperature of the liquid.

(viii) Calculate η using equation (1).

Observations and Calculations

(A) *Diameter of the disc by a scale.*

(i) ....cm, (ii) ....cm, (iii) ....cm.
Mean $D=$ ....cm; Mean $r=$ ....cm.

(B) *Thickness* (*d*) *of the disc by a scale gauge.*

Pitch of the screw gauge= ....cm.
Least count of screw gauge= ....cm.
Zero-error= ± ....cap. div.

No. of obs.	No. of complete rot. n	Complete rot.× pitch (cm)	Cap. reading	Corrected cap. read.	Total (cm)	Mean $=d$ (cm)
1	...	...	...	...	...	...
2	...	...	...	...	...	
3	...	...	...	...	...	

(C) *Density* (ρ) *of liquid determined by sp. gr. bottle.*

$\rho=$ ....gm/cm^3.

(D) *Time period T and T′.*

Body	Sl. No.	No. of complete oscillations	Time (sec)	Time period (sec)	Mean time period (sec)
Disc	1	50	...	...	... ($=T$)
	2	50	...	...	
	3	50	...	...	
Disc + ring	1	50	...	...	... ($=T'$)
	2	50	...	...	
	3	50	...	...	

(E) *Radius of the ring*=(i) ....cm, (ii) ....cm, (iii) ....cm.

Mean $a=$ ....cm.

Mass of the ring, $m=$ ....gm.

$$\therefore \quad I=\frac{T^2 ma^2}{T'^2-T^2}= \text{........gm-cm}^2.$$

(F) *To find the log. dec. in air* (λ_0).

Oscillations during first set			Time interval t (sec)	Time period T (sec)	No. of half vibrn. $n=2t/T$ (sec)	Oscillations during second set after time t sec			$\lambda_0=\frac{2\cdot 303}{n}\times\log_{10}\frac{\beta_1+\beta_2+\ldots+\beta_{10}}{\beta_{n+1}+\ldots+\beta_{n+10}}$
Displacement of spot towards		Total displacement of spot from left to right				Displacement of spot towards		Total displacement of spot from left to right	
Left	Right					Left	Right		
...(α_1)	...(α_2)	$\beta_1=\alpha_1+\alpha_2=\ldots$				...(α_1)	...(α_2)	$\beta_{n+1}=\alpha_1+\alpha_2=\ldots$	
...(α_3)	...(α_4)	$\beta_2=\alpha_3+\alpha_4=\ldots$				...(α_3)	...(α_4)	$\beta_{n+2}=\alpha_3+\alpha_4=\ldots$	
...(α_5)	...(α_6)	$\beta_3=\alpha_5+\alpha_6=\ldots$				...(α_5)	...(α_6)	$\beta_{n+3}=\alpha_5+\alpha_6=\ldots$	
...(α_7)	...(α_8)	$\beta_4=\alpha_7+\alpha_8=\ldots$				...(α_7)	...(α_8)	$\beta_{n+4}=\alpha_7+\alpha_8=\ldots$	
...(α_9)	...(α_{10})	$\beta_5=\alpha_9+\alpha_{10}=\ldots$	...	...	...	...(α_9)	...(α_{10})	$\beta_{n+5}=\alpha_9+\alpha_{10}=\ldots$	...
...(α_{11})	...(α_{12})	$\beta_6=\alpha_{11}+\alpha_{12}=\ldots$				...(α_{11})	...(α_{12})	$\beta_{n+6}=\alpha_{11}+\alpha_{12}=\ldots$	
...(α_{13})	...(α_{14})	$\beta_7=\alpha_{13}+\alpha_{14}=\ldots$				...(α_{13})	...(α_{14})	$\beta_{n+7}=\alpha_{13}+\alpha_{14}=\ldots$	
...(α_{15})	...(α_{16})	$\beta_8=\alpha_{15}+\alpha_{16}=\ldots$				...(α_{15})	...(α_{16})	$\beta_{n+8}=\alpha_{15}+\alpha_{16}=\ldots$	
...(α_{17})	...(α_{18})	$\beta_9=\alpha_{17}+\alpha_{18}=\ldots$				...(α_{17})	...(α_{18})	$\beta_{n+9}=\alpha_{17}+\alpha_{18}=\ldots$	
...(α_{19})	...(α_{20})	$\beta_{10}=\alpha_{19}+\alpha_{20}=\ldots$				...(α_{19})	...(α_{20})	$\beta_{n+10}=\alpha_{19}+\alpha_{20}=\ldots$	

(G) *To find log dec. in the liquid* (λ).

Tabulate as in (F).

(H) *Temperature of liquid*= . . . . °C.

$$\therefore \quad \eta=\frac{16I^2}{\pi\rho T(r^4+2r^3d)^2}\left\{\left(\frac{\lambda-\lambda_0}{\pi}\right)+\left(\frac{\lambda-\lambda_0}{\pi}\right)\right\}$$

= . . . . gm-cm^{-1} sec^{-1} (poise)

= . . . . SI unit.

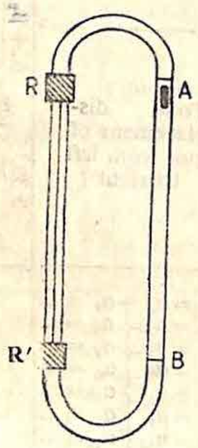
Result. η = ... SI unit.

Precautions. (i) The length and radius of suspension should be so choosen that the oscillation may not be too quick in air or too slow in liquid. (ii) As r occurs in high powers, it should be measured carefully.

EXPERIMENT 19. Determination of the viscosity of air by Rankine's method.

Apparatus. Rankine's apparatus, travelling microscope, stop-watch, mercury, watch-glass, beaker, weight-box, small glass-funnel, pieces of rubber tubing, metre scale, pinch-cock and crucible.

Description of the apparatus : RANKINE'S APPARATUS. This apparatus may be made by taking a length of quill tubing of from 3 to 3·5 mm bore. This is bent as in the fig. 1.35, and joined by rubber tubes *R* and *R′*, to a capillary tube of from 0·1 to 0·2 mm diameter and 50 cm long. The whole arrangment is then mounted on a board, so that it may be moved about with ease. Scratches *A* and *B* are made on the quill tubing so that the volume above *A* is the same as that below *B*. A pellet of *clean* mercury (about 5 cm long) is introduced into the tube *AB* before *R* is fitted in position.



(Fig. 1.35)

Theory. When the board is hold vertically, it causes the mercury pellet to descend in *AB*. This pushes the air in the tube through the capillary. If the time interval from the instant the upper surface of the pellet is at the upper mark (*A*) to the instant the lower surface is at the lower mark (*B*) is *t*, then

$$\frac{v}{t}=\frac{\pi}{8}\,\frac{p}{l}\,\frac{r^4}{\eta}, \qquad \cdots (1)$$

where v is the volume of gas passing through the tube in t seconds, p is the extra pressure due to the pellet, l is the length of the capillary tube, r is the radius of the capillary tube, and η is the viscosity of the gas (air) in the tube.

The difference in curvature of the two ends of the pellet introduces a surface tension effect which must be corrected for. The value of p is not mg/A, where m is the mass of the pellet, and A the mean cross-section of the tube, but in eqn. (1) above

$$p=\frac{mg}{A}-\epsilon$$

were ϵ is the amount of the total pressure accounted for by this surface tension effect. The value of ϵ is constant for a given tube and may be found by altering m. This is readily done by using different lengths of pellet in the full tube. The value of v/t is plotted against mg/A; this gives a straight line, indicating the constancy of ϵ, whose value is found from the intercept on the axis of mg/A.

Now if v_0 is the volume between the scratches A and B, as determined by the experiment,

$$v = v_0 - \frac{m}{\rho},$$

where ρ is the density of mercury. Therefore

$$\eta = \frac{\pi}{8} \frac{r^4}{l} \frac{\left(\frac{mg}{A} - \epsilon\right)t}{\left(v_0 - \frac{m}{\rho}\right)} \quad .. \ (2)$$

from which η may be calculated.

Procedure. (i) Clean and dry the capillary tube. Measure its length thrice by a metre scale and find out its mean value (l).

(ii) Attach a rubber tubing to one end of the cap. tube and dip the other end of it into clean and dry mercury. Close the free end of the rubber tube by pinch-cock and then press the rubber tube in the middle. Release the pressure. A mercury pellet will be drawn in closing the end of the cap. tube under mercury with finger, take out the tube from the mercury and place the tube flat on a horizontal base. Measure the length of the mercury pellet with a travelling microscope at different parts of the tube. Find out the length L in cm. Weigh an empty clean crucible. Empty the mercury into the crucible and reweigh it. The difference will give the mass of the mercury M in gm. Determine the value of r^2 (whence r^4) from the relation $M = \pi r^2 L\rho$, where ρ is the density of mercury at room temperature.

(iii) Clean and dry the wider tube. Measure its internal diameter thrice by travelling microscope and find out its mean radius (R). Then $A = \pi R^2$.

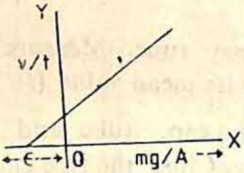
Also measure the distance between A and B thrice by metre scale and find out its mean value (L'). Then $v_0 = AL'$.

(iv) Now introduce a pellet of mercury about 5 cm long in the wider tube using small funnel attached with rubber tubing and pinch-cock. Measure the length (d) of the mercury pellet by travelling microscope taking readings at the two ends of it. Then $m = Ad\rho$.

(v) Attach the capillary tube with the wider tube by rubber tubing. Keep the tube horizontal on the board and bring the mercury pellet a few cm away from mark A. Now hold the board with the assembly to the vertical position. The pellet falls down driving air from AB into the cap. tube. Start the stop-watch when the top of the pellet crosses mark A and stop the watch when its bottom crosses the mark B. Note down the time of descent. Repeat this procedure twice more by inverting the board. Find out the mean time of descent (t) in sec.

(vi) Repeat the experiment five times by taking mercury pellets of different length into the wider tube and determine the mean time of descent for each pellet

(vii) Plot a graph of v/t against mg/A. This will be a straight line (fig. 1.36). The value of ϵ will be found out from the intercept on the x-axis.



(Fig. 1.36)

(viii) Now calculate η using relation (2).

Observations and Calculations

(A) *Length of the capillary tube.*

(i) ....cm, (ii) ....cm, (iii) ....cm.

Mean $l =$ ....cm.

Least count of travelling microscope = ...cm.

Length of the mercury pellet in the cap. tube :

(i) ....cm, (ii) ....cm, (iii) ....cm.

Mean $L =$ ....cm.

Mass of this mercury pellet $M =$ ....gm.

Density of mercury $\rho =$ ....gm/cm³ at......°C.

$\therefore \quad r^2 = m/\pi L\rho =$ ....cm², from which $r^4 =$ ....cm⁴.

(**B**) *Internal diameter of the wider bore as measured by travelling microscope.* (i) ....cm, (ii) ....cm, (iii) ....cm.

Mean $R =$ ....cm.

$\therefore$ Mean cross-section of the wider tube $A = \pi R^2 =$ ....cm².

Distance between two marks A and B :

(i) ....cm, (ii) ....cm, (iii) ....cm.

$\therefore$ Mean $L' =$ ....cm, whence $v_0 = AL' =$ ....cm³.

(C) *Length* (*d*) *of the mercury pellete in the wider tube.*

Pellet No.	Microscope reading in cm						Difference $=d$ (cm)	Mass of pellet $m=Ad\rho$ (gm)
	Left end of pellet			Right end of pellet				
	M.S.	Ver.	Total	M.S.	Ver.	Total		
1	...	...	...	...	...	...	...	...$(=m_1)$
2	...	...	...	...	...	...	...	...$(=m_2)$
3	...	...	...	...	...	...	...	...$(=m_3)$
4	...	...	...	...	...	...	...	...$(=m_4)$
5	...	...	...	...	...	...	...	...$(=m_5)$

(D) *Time of descent* (*t*).

Pellet No.	Mass of the pellet $=m$ (gm)	mg/A (dyn /cm²)	Time of descent of the pellet from A to $B=t$, in sec				$v=v_0-\frac{m}{\rho}$ (cm)	v/t (cm³/sec)
			I	II	III	Mean		
1	$m_1=$...	...	...	...	...	...$(=t_1)$	...$(=v_1)$	...$(=v_1/t_1)$
2	$m_2=$...	...	...	...	...	...$(=t_2)$	...$(=v_2)$	...$(=v_2/t_2)$
3	$m_3=$...	...	...	..	...	...$(=t_3)$	...$(=v_3)$	...$(=v_3/t_3)$
4	$m_4=$...	...	...	...	...	...$(=t_4)$	...$(=v_4)$	...$(=v_4/t_4)$
5	$m_5=$...	...	...	...	...	...$(=t_5)$	...$(=v_5)$	...$(=v_5/t_5)$

(E) *From* $\left(\frac{v}{t}-mg\right)$ *graph* : $\epsilon=$ ....dynes/cm².

$$\therefore \quad \eta=\frac{\pi}{8}\frac{r^4}{l}\frac{\left(\frac{mg}{A}-\epsilon\right)t}{\left(v_0-\frac{m}{\rho}\right)}=\ldots\ldots\text{poise}$$

$$=\ldots\ldots\text{SI unit.}$$

Result. $\eta=$ ....SI unit at........°C.

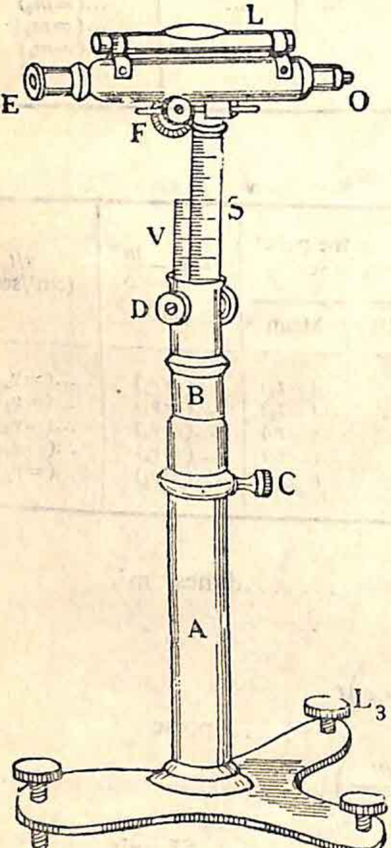
Precautions. (i) The tubes must be cleaned and dried. (ii) As the radius of the cap. tube occurs in fourth power, the radius should be measured very carefully. (iii) The time of descent of the pellet should be noted carefully by an accurate stop-watch.

SURFACE TENSION

EXPERIMENT 20. Determination of surface tension of water by rise in a capillary tube.

Apparatus. Glass tubes, glass trough, glass plate, needle, cathetometer microscope, micrometer scale, thermometer, plumb line.

Description of the apparatus : CATHETOMETER MICROSCOPE. It consists of a metal tube *A* fixed on a heavy metal frame provided with three levelling screws L_1, L_2, L_3. Another tube *B* passes into the tube *A* The microscope *M* is mounted horizontally on the pillar *S* having triangular cross-section, which can be raised up or lowered down by turning the milled head screw *D*. The pillar has a scale *S* engraved on it which moves by the side of the vernier *V* fixed to the tube *B*. *F* is another milled head by which the microscope can be moved forward or backward. The tube *B* can also be pulled out of the tube *A* and can be fixed at any required height by clamping the screw *C*. A spirit level *L* is mounted on the top of the microscope with its one end fixed, while its other end can be slightly raised by means of adjusting nuts. *E* and *O* are the eye-piece and objective of the microscope respectively. *E* is provided with cross-wires or a scale which facilitates the measurement of small objects. To know the actual length, the eye-piece scale has to be calibrated with a micrometer scale. The microscope can also be rotated about a vertical axis so that it can be made to point in any direction. The magnification of



(Fig. 1.37)

the microscope can be altered by changing the tube length. The cathetometer is used for measuring vertical height.

Theory. The weight of the column of liquid below the meniscus in the capillary tube is supported by the upward forces of surface tension acting around the circumference of the circle of contact. That is, $2\pi rT=\pi r^2 h\rho g$. With very fine capillary tubes, the meniscus surface may be considered to be hemispherical and the weight of liquid above the lowest point of the meniscus is

$$(\pi r^3-\tfrac{2}{3}\pi r^3)\rho g=\tfrac{1}{3}\pi r^3\rho g.$$

Hence,
$$2\pi rT=\pi r^2 h\,\rho g+\tfrac{1}{3}\,\pi r^3\,\rho g$$

or
$$T=\tfrac{1}{2}\rho gr\left(h+\frac{r}{3}\right),$$

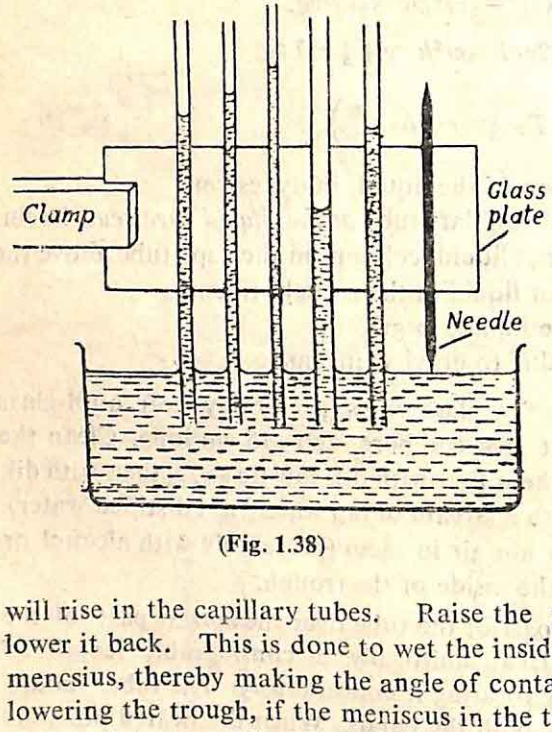
where T = surface tension of the liquid, in dynes/cm,
r = radius of the capillary tube *at the liquid meniscus*, in cm,
h = height of the liquid column in the cap. tube above the free surface of liquid in the trough, in cm,
ρ = density of the liquid, in gm/cc
and, g = acceleration due to gravity, in cm/sec^2.

Procedure. (i) Take a few glass tubes (preferably soft quill-glass tubing), each of about 0·8 cm bore and 15 cm long. Clean the glass tubes by washing them first with dil. caustic soda, then with dil. nitric acid and finally with a stream of tap water (not distilled water). Dry the tubes by passing hot air in them (preferably with alcohol or ether). Similarly clean the inside of the trough.

(ii) Place the middle part of the tube over the *hottest* part of the flame of the gas burner. Heat uniformly a considerable length of it in the middle region by rotating it continuously. The tube should be held horizontally by both the hands. When the heated portions have become soft (indicated by the signs of bending), remove it from the flame and pull apart the ends at first *slowly*, and then more quickly till the desired bore of capillary is produced. Immediately after drawing, the tube should be kept vertical to avoid bending by the action of gravity. The capillary tube would be wide or narrow according as the pull is slow or quick. From the central portion cut out a piece about 10 cm long. Draw a few more (at least five) capillary tubes. The bore should be uniform. The bore should be about 1 mm in diameter.

(iii) Take a clean glass plate (3 cm × 8 cm approx.) and fix the cap. tubes with soft wax so that they are parallel and project equally on one side of the plate. The distance of separation between two neighbouring tubes should be nearly 1 cm. Next fix a needle (about 5 cm long) so that its one end projects a little less (2 to 3 cm) than the projected ends of the tubes. The needle should not be fixed very close to the tube so that capillary action between the needle and its adjacent tube may not arise.

(iv) Fill the clean trough with *fresh tap water*. Next clamp the glass plate over the surface of water in the trough so that the tubes and needle are vertical. Test this with a plumb line. Adjust the height so that the lower tip of the needle *just* touches the water surface (test it by seeing the reflection of needle in water) and the lower ends of the tubes are well immersed in the water. The water will rise in the capillary tubes. Raise the trough about 1 cm and lower it back. This is done to wet the inside of each tube above the mencsius, thereby making the angle of contact equal to zero. After lowering the trough, if the meniscus in the tube does not come back to its original position, the tube is dirty and should be rejected.



(Fig. 1.38)

(v) Place a cathetometer microscope close to the tubes so that it can be focussed on them. Level the cathetometer to make its axis horizontal. Suspend a plumb line and focus the microscope on it. Rotate the scale in the eye-piece till the image of the thread is parallel to the eye-piece scale. (If the microscope is provided with cross-wires, make the vertical cross-wire parallel to the image of the thread.)

(vi) Now focus the microscope on the water level in the first tube and adjust the height so that any eye-piece scale division is tangential to the lowest point of the meniscus (or the horizontal cross-wire is tangential to the lowest point of the meniscus). Read the position of the zero of the vernier over the *vertical scale* of the microscope. Similarly take readings corresponding to the lowest points of the meniscus in the second, third, etc. tubes. Remember that the *same* eye-piece scale division should be tangential to the lowest point of meniscus in each tube. Next adjust the micrsope on the upper tip of the needle. The same eye-piece scale division should be tangential to the upper tip of the needle. Read the position of the zero of the vernier over the vertical scale of the microscope. Find out the difference x between the readings of the needle's upper tip and bottom of the meniscus in each tube. If l be the length of the needle then the height of the meniscus is given by, $h=l \pm x$ (+ve or −ve sign should be taken according as the upper tip of the needle is *below* or *above* the meniscus).

(vii) By means of ink-dot on the outer surface, mark the position of the bottom of meniscus in each tube. Remove the water trough and then measure the length of the needle l.

(viii) Remove each tube and cut* it at the mark by a sharp file or better by a fine grained sand paper. Fix it horizontally in a stand so that the cut end is directed towards the microscope. Measure the diameter of the bore on the eye-piece scale† along two mutually perpendicular directions. Repeat the process with the other tubes also.

(ix) Take a micrometer scale and mount it on a suitable stand. The micrometer scale consists of a rectangular glass plate at the centre of which a length usually 1 mm long is divided into 100 equal parts. Hence the divisions are not visible by naked eye. Illuminate it with an etectric lamp placed on one side of it but not directly behind it. Focus the microscope on the scale avoiding parallax and by comparison determine the value of 1 division of the eye-piece scale. Take three readings and find the mean. Then convert the readings of the diameters in cm. [If the microscope provided with cross-wires is employed, omit this operation.]

(x) Note down the temperature of water in trough and find out the density of water (ρ) at that temperature from a book of constants (For other liquids ρ has to be determined separately with a specific gravity bottle.)

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*Under no circumstance should the tube be broken by bending, otherwise the fracture will be uneven.

† or directly on vertical scale by setting the crosswire tangential to the inner boundary line of the section.

(xi) Plot a graph taking r, in cm along x-axis and $\left(h+\frac{r}{3}\right)$, in cm along y-axis (fig. 1.39). This will be a rectangular hyperbola.

Observations and Calculations

Enter thus—

(A) *Temperature of water.*

Initial temperature of water, t_1°C = ...°C.
Final temperature of water, t_2°C = ...°C.
∴ Mean temperature of water during experiment,

$$t°\text{C}=\frac{t_1°+t_2°}{2}=27°\text{C}.$$

(B) *Density of water at* 27°C (t°C), $\rho=0{\cdot}9964$ gm/cc.

(C) *Readings for the determination of the length of the needle.*

1 main scale division of the microscope = ...cm.
....vernier divisions coincide with....main scale divisions.
∴ 1 ver. divn. = ...cm.
∴ Least count = 1 M.S. − 1 v.d. = ...cm.

No. of obs.	Reading of lower tip of needle			Reading of upper tip of needle			Difference in cm	Mean length of the needle l in cm
	M.S. in cm	Ver.	Total in cm	M.S. in cm	Ver.	Total in cm		
1	...	...	...	...	...	...	...	8·2
2	...	...	...	...	...	...	...	
3	...	...	...	...	...	...	...	

(D) *Readings for the determination of h*

Tube no.	Reading of upper tip of needle			Reading of bottom of meniscus			Difference in cm $=x=A\sim B$	Height in cm of the meniscus $=h=l\pm x$
	M.S. in cm	Ver.	Total in cm (A)	M.S. in cm	Ver.	Total in cm (B)		
1			4·05			2·26	1·79	6·14
2			4·05			4·33	0·28	8·48
3			4·05			6·97	2·92	11·12
4			4·05			2·47	1·58	6·62
5			4·05			2·82	1·23	6·97

(E) *Readings for the determination of diameter* (2*r*).

Tube no.	Measurement of diameter (2r)				Calibration of eye-piece scale		
	Diameter in eye-piece scale divisions			Value of Mean in mm	Eye-piece scale divisions	Micrometer scale divisions	Value of eye-piece scale divisions in mm
	Direct	Cross	Mean				
1	11	11	11	0·451			
2	8	9	8·5	0·3485			
3	6	7	6·5	0·2665			0·041
4	10	11	11·5	0·4305			
5	10	10	10	0·410			

If the eye-piece is provided with cross-wires, use this table :

Tube no.	No. of obs.	Reading of lower end			Reading of upper end			Diameter in cm	Mean in cm $=2r$
		M.S. in cm	Ver.	Total in cm	M.S. in cm	Ver.	Total in cm		
1	Direct	...	...	...	...	...	...	...	...
	Cross	...	...	...	...	...	...	...	...
2									
...									

(F) *Calculations.*

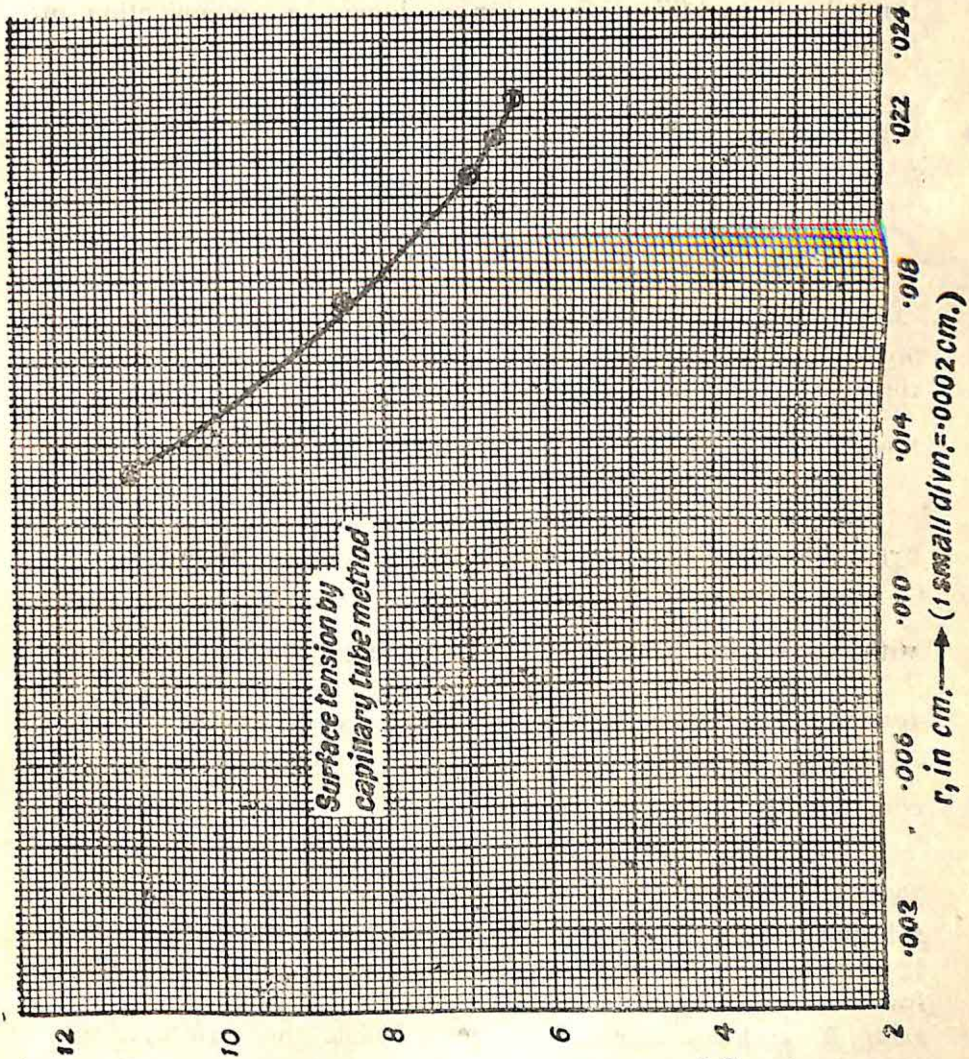
Tube no.	h in cm	r in cm	$\left(h+\frac{r}{3}\right)$ in cm	$\left(h+\frac{r}{3}\right).$ in sq cm	Surface tension $T=\frac{1}{3}\rho gr\left(h+\frac{r}{3}\right)$ in dynes/cm	Mean surface tension in dynes/cm	Temp. of water in °C = t°C
1	6·41	·0225	6·4175	0 1444	70·52	70·92	27°C
2	8·48	·01742	6·4858	0·1478	72·18		
3	11·12	·01333	11·1244	0·1460	72·40		
4	6·62	·02152	6·62717	0·1426	69·68		
5	6·97	·0205	6·9768	0·1430	69·84		

Result. The surface tension of water at 27°C = 70·92 dynes/cm
= $70{\cdot}92 \times 10^3$ N/m.

Standard value = ... dynes/cm = ...N/m.

Conclusion. The value of $\left(h+\frac{r}{3}\right).\, r$ is almost constant. This verifies the Jurin's Law. It is also verified by the nature of the graph (Fig. 1.39).

Precautions. (i) Since the rise of water (liquid) in the cap. tube depends on the radius of the tube at which the meniscus stands, the radius of the tube should be measured at the meniscus. As it is difficult to cut the tube *exactly* at the position of meniscus, the tube should be of as uniform bore as possible. (ii) The diameter of the bore should be measured very carefully. (iii) The tubes, needle and the eye-piece scale should be vertical. (iv) The back-lash error with the microscope should be avoided by always rotating the screw in the same direction. (v) Since any trace of grease or oil reduces the value of surface tension considerably, fresh tap water (and not distilled water as it contains traces of grease) should be taken in the trough. The water should not be contaminated by hands or wax. After cleaning, avoid touching by hand the inside of the trough. (vi) Since the value of surface tension falls with the rise of temperature, the latter should be noted and reported with the result.



(Fig. 1.39)

Discussion. This is one of the best practical methods of determining T of a liquid *which wets the walls of the tube*, i.e. for which angle of contact is zero (e.g. water, aqueous solutions, alcohol etc.). However this method suffers from a number of disadvantages, viz. (i) difficulty in measuring the radius of the bore exactly at the meniscus, (ii) difficulty in getting capillary tube of absolutely uniform bore throughout, and (iii) difficulty in avoiding the contamination of liquid.

Note. Travelling microscope also can be employed in place of cathetometer microscope.

ASSOCIATED EXPERIMENTS

1. *Veriy Jurin's Law*

Hint. Jurin's law states that the elevation or depression of a liquid in a capillary tube is inversely proportional to the radius of the tube at the place of contact (meniscus). Hence according to this law $\left(h+\frac{r}{3}\right).r$ should remain constant. So, perform the above experiment and show $\left(h+\frac{r}{3}\right).r$ a constant. Also draw a graph with r as abscissa and $\left(h+\frac{r}{3}\right)$ as ordinate. The graph would be found to be a rectangular hyperbola which also verifies the law.

2. *Show how the surface tension of a solution varies with concentration.*

Hint. Make the salt solution by dissolving 10 gm of salt in 200 gm of water. Now perform the above experiment, using this solution in place of water (in the trough). Now dissolve every time 10 gm of salt in the same solution and repeat the above experiment for five concentrations. Also determine the density at that temperature for each concentration. Then calculate the surface tension of each concentration. Now plot a graph taking concentration (mass of salt dissolved per 100 gm of water) along the x-axis and surface tension (dynes/cm) along the y-axis. In fact there is no simple relation connecting the variation of surface tension with concentration.

EXPERIMENT 21. Determination of the surface tension of a liquid at different temperatures by Jaeger's method.

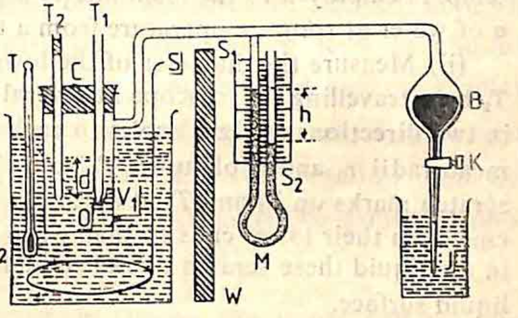
Apparatus. Jaeger's apparatus, a travelling microscope, specific gravity bottle, weight-box, balance, stopper, thermometer.

Description of the apparatus : JAEGER'S APPARATUS. It is shown in fig. 1.40. Two clean glass tube, one T_2 of internal diameter about 1·2 mm, while the other T_1 is a similar tube drawn out to a fine capillary, of about 0·2 mm diameter, at its lower end O. Both the tubes are introduced vertically through the rubber cork C of the vessel V_1 and their lower ends dip into the experimental liquid taken in V_1. To ensure that the lower ends of both T_1 and T_2 are at the same depth d below the liquid level in V_1, scratch marks are made on T_1 and T_2 at the same distance d from their lower ends. These scratch marks are always made to coincide with the liquid surface. The vessel V_1 is kept in a water bath V_2 whose temperature can be changed to make the temperature of liquid in V_1 to different values. The upper part of the vessel V_1 is connected to a manometer M containing a very light liquid (xylol or water) and a mercury suction bulb B provided with stop-cock K and a capillary jet J. A wooden screen W is kept between V_2 and M, so that the rest of the apparatus may be screened from V_2.

Theory. If an air bubble of radius r be formed at a depth d inside a liquid of density ρ, then the excess pressure p inside the bubble over that existing at its outer surface is given by

$$p=2T/r \qquad ..(1)$$

where T is the surface tension of liquid at a certain temperature. In this arrangement, atmospheric air under a pressure P enters the tube T_1 (or T_2) due to the lowering of pressure on the liquid surface in V_1 by $h\sigma g$ from the atmospheric pressure P. Here h is the maximum difference in the levels of manometric liquid of density σ, in the two arms of the manometer just before the air bubble at the end of T_1 (or T_2) breaks. Hence



(Fig. 1.40)

$$\text{pressure inside the bubble,} \quad p_1=P$$

$$\text{pressure outside the bubble,} \quad p_2=P-h\sigma g+d\rho g.$$

Thus the excess pressure inside the bubble over that existing at its outer surface is

$$p = p_1 - p_2 = g(h\sigma - d\rho) \quad .. (2)$$

from which

$$\frac{2T}{r} = g(h\sigma - d\rho). \quad .. (3)$$

If h_1 and h_2 be the maximum differences in the liquid levels of the manometer just before the bubbles break at the ends of tubes T_1 and T_2 having radii r_1 and r_2 respectively, then

$$\frac{2T}{r_1} = g(h_1\sigma - d\rho) \text{ and } \frac{2T}{r_2} = g(h_2\sigma - d\rho)$$

whence

$$T = \frac{g\sigma r_1 r_2 (h_1 - h_2)}{2(r_2 - r_1)}. \quad .. (4)$$

The eqn. (4) may be used to find the surface tension of the liquid at its different temperatures.

Procedure. (i) Determine the specific gravity σ of the liquid used in the manometer by a specific gravity bottle. If water at room temp. is employed as the manomertic liquid then find out the density σ of water at room temperature from a table.

(ii) Measure the diameter of the lower ends of the tubes T_1 and T_2 by a travelling microscope at several places and at each place in two directions at right angles to each other. Then find out the mean radii r_1 and r_2 of tubes T_1 and T_2 respectively. Make two scratch marks on T_1 and T_2 at a certain constant distance d (4 or 5 cm) from their lower ends so that when they should be introduced in the liquid these scratch marks should be kept coincident with the liquid surface.

(iii) Fill nearly half the vessel V_1 with the given liquid and introduce a major part of it into the water-bath of V_2. Introduce the tubes T_1 and T_2 vertically through the rubber cork C at the mouth of V_1, so that the scratch marks on T_1 and T_2 may remain coincident with the liquid surface of V_1. Introduce a thermometer T (reading 0·1°C) in the water of V_2 to record its temperature. Also introduce a stirrer S in V_2 for stirring the water in it.

(iv) Close the upper end of tube T_2 by a stopper while keep open that of T_1 for the admittance of atomospheric air. Taking starting temperature of water in V_2 as that of room, note down the temp. from the thermometer after stirring well with the stirrer.

(v) Open the stop-cock K by a very small amount so that mercury from the bulb B goes out at a slow rate and reduces the air pressure on the liquid surface in V_1 very slowly. This reduction of pressure will be indicated by the creation of difference of liquid levels in the two arms of the manometer. Outer air will now enter in T_1 and will begin to form a bubble at the end O of the tube T_1. As the air pressure in B and hence in V_1 is reduced more and more, the size of the bubble as well as the difference of liquid levels in the two arms of manometer begin to increase. Constantly observe the liquid levels is the two arms of the manometer by a microscope. Just before the bubble breaks, liquid level in one arm assumes highest position while that in the other arm assumes a lowest position. Open the stop-cock K to such an extent that bubbles are formed at the rate of one in 10 seconds. Coincide horizontal cross-wire of microscope with the highest liquid level in one arm of manometer for a number of bubbles and note this highest level from the scale S_1S_2 or better from the vernier of the microscope. Similarly coincide the horizontal cross-wire with the lowest liquid level in another arm of the manometer for a number of bubble and note the reading corresponding to this lowest level either from the scale S_1S_2 or from the vernier of the microscope. From these two readings find the maximum difference of liquid levels (h_1) in the two arms of manometer when the bubble breaks at the end of T_1.

(vi) Repeat the operation (v) by closing the upper end of tube T_1 and keeping open the upper end of T_2. Find out the maximum difference of the liquid levels (h_2) in the two arms of manometer for the tube T_2. Calculate the surface tension (T) at room temperature from the relation (4).

(vii) Repeat operation (v) and (vi) by raising the temperature of water in V_2 to different values by steps of 5°C. At each step, maintain the temperature of water in V_2 constant by manipulating the burner and by increasing the capacity of V_2 so that an appreciable amount of water may be taken in it.

(viii) Now draw graph with the temperature (t) of liquid in °C along x-axis and the surface tension (T) of the liquid at that temperature in dynes/cm (or N/m) along y-axis. This graph will show the variation of surface tension of liquid with temperature.

Observations and Calculations

(A) *Determination of density* (σ) *of manometric liquid.*

Wt. of clean sp. gr. bottle + water at room temp. $W_1 = \ldots$ gm.
Wt. of clean sp. gr. bottle + liquid at room temp. $W_2 = \ldots$ gm.
Wt. of dry empty sp. gr. bottle $W_3 = \ldots$ gm.

$$\therefore \quad \sigma = \frac{W_2 - W_3}{W_1 - W_3} \times \rho_t = \ldots \text{gm/cm}^3.$$

Where ρ_t is the density of water at room temp. .... °C.

(B) *Determination of the diameters of the lower ends of* T_1 *and* T_2 *by travelling microscope.*

.... ver. divn. = ... M.S. divn.
Value of 1 M.S. divn. = ... mm = ... cm.
∴ L.C. = ... cm.

Tube no.	No. of obs.	M.S. (cm)	Ver. reading	Ver. reading ×L.C. (cm)	Total (cm)	Mean diam. (cm)	Mean radius (cm)
	1. D	...	...	...	...		
	1. C	...	...	...	...		
T_1	2. D	...	...	...	...	...	...
	2. C	...	...	...	...		$(=r_1)$
	3. D	...	...	...	...		
	3. C	...	...	...	...		
	1. D	...	...	...	...		
	1. C	...	...	...	...		
T_2	...	...	...	...	...	...	... $(=r_2)$
	3. D	...	...	...	...		
	3. C	...	...	...	...		

(C) *Record of temperature and difference of liquid levels in manometer.*

Temp. of bath (°C)	Depth of ends of T_1 and T_2 (cm)	Tube used	No. of bubbles observed	Constant highest reading of liquid level in one arm of manometer (cm)	Constant lowest reading of liquid level in another arm of manometer (cm)	Difference of liquid levels in the two arms of manometer for a given tube $h=R_1-R_2$ (cm)	(h_1-h_2) in cm
...... (room temp.)	......	T_1	1	...	...		
			2	...	...		
			3	...	...		
			4	...	...	......(h_1)	
			5	... constant R_1	... constant R_2		
	(d)		6	...	...		
		T_2	1	...	...		......
			2	...	...		
			3	...	...		
			4	...	...		
			5	... constant R_1	... constant R_2	......(h_2)	
			6	...	...		
...... (room temp. +5°C)	......	T_1		...(R_1)	...(R_2)	......(h_1)	
	(d_1)	T_2		...(R_1)	...(R_2)	......(h_2)	......
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.

(D) *Temperature-Surface tension relation.*

Temp. of bath in °C	Density of manometric liquid (σ) in gm/cm²	Radius of T_1 in cm (r_1)	Radius of T_2 in cm (r_2)	(h_1-h_2) in cm	$T=\frac{g\sigma r_1 r_2(h_1-h_2)}{2(r_2-r_1)}$ in dynes/cm
...... (room temp.)	......	......	......	......	....
...... (room temp. +5°C)	......	......	......	......	....
etc.	etc.	etc.	etc.	etc.	etc.

(E) *Drawing of (t-T) graph.*

Precautions. (i) The tubes T_1 and T_2 should be clean and free from traces of grease. (ii) The diameter of tube T_1 should be measured very carefully, otherwise a small error in its measurement will cause a large percentage error in the value of surface tension. (iii) Temperature of the bath should be maintained steady during each set of experiment. (iv) The apparatus should be airtight and tubes should be selected so that their bores at the lower end are circular.

Discussions. (i) By employing two tubes, density of liquid (ρ) is eliminated and thereby the trouble of finding the density of liquid at different temperatures is avoided.

(ii) As two tubes are used, it is not essential that the liquid surface in the vesel V_1 should be flat. Hence a smaller container may be employed.

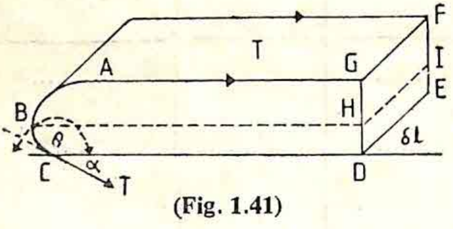
(iii) The maximum difference of levels of liquid in the two arms of manometer is independent of the rate of formation of bubble provided it is not very rapid.

(iv) The assumption that the radius of the bubble is equal to that of the ends of the tubes is justifiable when the radius of the tube is small.

(v) Greater the value of r_1 greater will be the percentage error in the value of surface tension. Hence to minimise the error in the measurement of surface tension the diameter ($2r_1$) of the tube T_1 should be small, say 0·2 mm.

EXPREIMENT 22. **Determination of the surface tension and angle of contact for mercury by Quincke's method.**

Apparatus. Sheet of glass plate, three levelling jacks, spirit-level, clean dry mercury, lycopodium powder, travelling microscope.



(Fig. 1.41)

Theory. Let θ be the angle of contact and α the supplement of θ.

Let $GH = h_1$ and $GD = h_2$.

Consider a section of the drop of width δl with vertical faces.

BHI is a horizontal

section through B, the point of maximum curvature (where the tangent plane to the drop is vertical).

Consider first the equilibrium of the horizontal faces on the portion of the drop above the section through B. The pull of surface tension inwards balance the hydrostatic thrust on the area $FGHI$,

i.e., $$T\delta l = g\rho\delta l\int_0^{h_1} h.dh = g\rho\delta l\ \frac{h_1^2}{2};$$

$$\therefore\ T = g\rho\frac{h_1^2}{2} \quad .. \quad (1).$$

Consider now the equilibrium of the whole slab, the inward forces due to surface tension balance the outward hydrostatic thrust on the area $DEFG$,

i.e. $$T\delta l + T\delta l \cos\alpha = g\rho\delta l\int_0^{h_2} h.dh = g\rho\delta l\,\frac{h_2^2}{2};$$

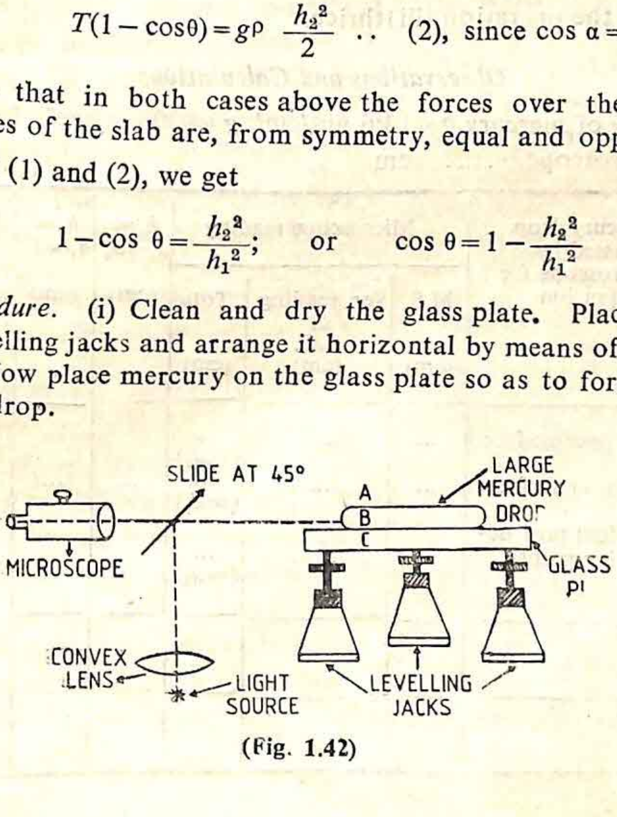
$$\therefore\quad T(1-\cos\theta) = g\rho\ \frac{h_2^2}{2} \ .. \ (2), \text{ since } \cos\alpha = -\cos\theta.$$

Note that in both cases above the forces over the front and back faces of the slab are, from symmetry, equal and opposite.

From (1) and (2), we get

$$1-\cos\theta = \frac{h_2^2}{h_1^2}; \quad \text{or} \quad \cos\theta = 1-\frac{h_2^2}{h_1^2} \quad .. \quad (3).$$

Procedure. (i) Clean and dry the glass plate. Place it on the three levelling jacks and arrange it horizontal by means of the spirit-level. Now place mercury on the glass plate so as to form a large circular drop.



(Fig. 1.42)

(ii) Scatter some lycopodium powder on the top of the mercury drop. Now focus the cross-wires of the travelling microscope on the upper surface (i.e. lycopodium powder) (A) of the drop and note the reading of the microscope. Then focus the cross-wires of the microscope on the lower surface (C) of the drop and note the reading of the microscope. The difference of these two readings will give the thickness (h_2) of the drop.

Repeat the operation (ii) three times.

(iii) Now place a microscope slide (glass plate) at 45° in front of the objective of the microscope and illuminate the slide by a lamp (light source) at 90° with the line of vision (fig. 1.42). Now focus the cross-wires of the microscope on the maximum curvature part (B) of the drop. On focussing the microscope a thin bright horizontal line is seen at B. Adjust the microscope until this bright horizontal line coincides with the horizontal cross-wire of the eye-piece and note the reading of the microscope. The difference of the first reading in (ii) and this reading will give the depth of the point of maximum curvature (h_1) below the upper surface of the drop.

Repeat the operation (iii) thrice.

Observations and Calculations

Density of mercury $\rho = 13{\cdot}6$ gm/cm^3, $g = 980$ cm/sec^2. Least count of the microscope = ...cm.

Set No.	Mercury drop focussed by microscope for the portion	Microscope reading			$h_2 = d_1 \sim d_2$	$h_1 = d_1 \sim d_3$	Mean h_2	Mean h_1
		M.S. (cm)	Ver. reading $\times$ L.C. (cm)	Total (cm)	(cm)	(cm)	(cm)	(cm)
I	1. Upper surface	...	......	... $(=d_1)$	...	...	...	...
	2. Lower surface	...	......	... $(=d_2)$				
	3. Most protruding point	...	......	... $(=d_3)$				
II								
III								

$$T=g\rho\ \frac{h_1^2}{2}=\ldots\ldots\ldots\ \text{dynes/cm}=\ldots\text{.Nm}^{-1}.$$

$$\cos\theta=1-\frac{h_2^2}{h_1^2}=\ldots\ldots,\ \therefore\ \ \theta=\ldots\text{.degree.}$$

Result. Surface tension T of mercury = ...Nm^{-1},
Angle of contact θ = ...degree.

Precautions. (i) The glass plate should be clean and dry. (ii) The glass plate should be horizontal. (iii) The reading for the most protruding part of the mercury drop should be taken very carefully.

EXPERIMENT 23. Determination of surface tension of soap solution from measurements of bubbles.

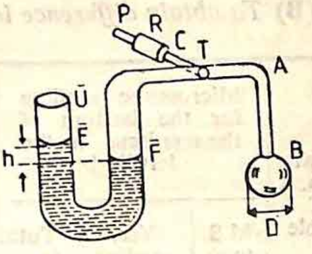
Apparatus. U-tube apparatus, travelling microscope, glycerine soap, watch glass, thermometer.

Description of the apparatus. U-TUBE APPARATUS. This consists of a fairly wide U-tube, containing water, sealed to a T-piece, T. One arm of the T-piece is bent at right angles and terminates at B, where AB is parallel to the U-tube limbs (fig. 1.43). To the other arm at C is attached a piece of rubber tube, R, having a glass rod, P, which just fits it, and which can act as a piston.

Theory. The excess prerssure (p) inside a soap-bubble of radius (r) is given by

$$P=\frac{4T}{r}\quad ..\quad (1),$$

where T is the surface tension of the soap-solution.



(Fig. 1.43)

Procedure: (i) Withdraw the piston P and immerse the end B in the soap-solution taken in the watch-glass. Then advance P slightly, causing a bubble to form at B. Drain the excess of soap-solution off this bubble by touching the drop at the bottom with a pencil, or with the side of the watch glass. Further advance the rod (piston) so that a bubble of, say, 1 to 2 cm diameter is blown. It will be noticed that the water in the U-tube takes up a position as in the fig. 1.43 indicating a pressure inside the bubble excess of the atmospheric pressure.

(ii) Measure this difference in level (h) using a travelling microscope and noting the readings of vernier of the vertical scale.

(iii) Then move the microscope until the bubble is focussed. Bring first the image of one side, and then the other, into coincidence with the vertical cross-wire of the eye-piece and note for both the readings of vernier of the horizontal scale. The difference in readings will give the diameter (d) of the bubble. Then $r = d/2$.

(iv) Calculate the excess pressure p using $p = hg$ dynes/cm^2 for a water manometer. Also calculate T using the relation (1).

(v) Repeat the experiment for bubble of different radii and obtain the mean of T.

Observations and Calculations

Temperature of the soap-solution = ... °C.

(A) *Least count of the microscope for the vertical scale* = ... cm.

Least count of the microscope for the horizontal scale = ... cm.

(B) *To obtain difference in level* (h).

Serial no. of bubble	Microscope reading for the bottom of the meniscus in the left limb			Microscope reading for the bottom of the meniscus in the right limb			Difference $= h$ (cm)	Excess pressure $p = hg$ (dynes/cm^2)
	M.S. (cm)	Ver. reading × L.C. (cm)	Total (cm)	M.S. (cm)	Ver. reading × L.C. (cm)	Total (cm)		
1	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...

(C) *To obtain radius of the bubble* (r).

Serial no. of bubble	Microscope reading for the left side of the bubble			Microscope reading for the right side of the bubble			Difference = dimeter, d (cm)	Radius $r=d/2$ (cm)	$T=\frac{hgr}{4}$ (dyne/cm)
	M.S. (cm)	Ver. reading ×L.C. (cm)	Total (cm)	M.S. (cm)	Ver. reading ×L.C. (cm)	Total (cm)			
1	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...

Mean $T=\ldots\ldots$dynes/cm$=\ldots\ldots$N/m.

Result. $T=\ldots\ldots$N m^{-1} at$\ldots\ldots\ldots$°C.

Precautions. (i) As the value of h is small, it should be measured very carefully. (ii) Bubbles of small radii should be blown. If the radii are large, excess pressure will be small and cannot be measured correctly. (iii) Radii of the bubbles should be measured very carefully.

Note. Excess pressure $p=hg\rho_t$ may be used for better accuracy where ρ_t is the density of water at room temperature.

* * *

and M_2 on the table in front of the scratch marks P and Q respectively, such that they can be moved parallel to the axis of the metal tube. Level them properly and then focus the microscopes on each scratch mark on the metal tube and make the interecsection of the cross-wires coincident with one edge of scratch. See that there is no parallax between the cross-wires and the image of the mark. Take the readings of both the microscopes in this position and repeat the operation five times. To avoid the back-lash error, the microscopes should be moved outwards each time while setting the cross-wires on the mark. Now, note the readings of the thermometer T_1 and T_2. The mean of their values is taken as the initial temperature (t_1°C).

(v) Place the burners below the boilers, and see that arrangement is not disturbed. Allow the steam to enter through both the side tubes P_1 and P_2 into the metal tube. The heating of the tube increases its length. The scratch marks are displaced outward from their positions. When the readings of both the thermometers are constant at least for ten minutes, record them. The mean of the two readings is the final temp. t_2°C. Now, move microscope tube at one end outward and see that the image of the same edge of the scratch mark is coinciding with the intersection of cross-wires again. Do the same thing at the other end. The difference between the final and the initial readings of the microscope at each end will give the increase at that end. The total increase will be the sum of the increments at two ends.

(iv) Record the readings as shown below and hence, calculate the mean co-efficient of linear expansion of the material of the tube.

Observations and Calculations

Metal of the rod........

(A) *Determination of the length of the rod.*

$l=$(i) 100·1 + (ii) 100·1 + (iii) 100·1 $\doteq$ 100·1 cm.

(B) *Determination of the Least counts of microscopes.*

(i) *Left-hand microscope*

Smallest horizontal scale division = 1 mm.
20 v. d. = 19 m. s. d.

(ii) *Right-hand microscope*

Smallest horizontal scale division = $\frac{1}{2}$ mm.
50 v. d. = 49 m. s. d.

$\therefore$ L.C. $= \frac{1}{20}$ s. d. $= \frac{1}{200}$ cm.

$\therefore$ L.C. $= 0{\cdot}005$ cm.

$\therefore$ L.C. $= \frac{1}{50}$ s.d. $= \frac{1}{100}$ mm.
$= \frac{1}{1000}$ cm.

$\therefore$ L.C. $= 0{\cdot}001$ cm.

(C) *Initial temp.* = ...°C; Final temp. = ...°C.

(D) *Readings of the screw marks.*

One End

No. of obs.	Left end Reading				Right end Reading				Diff. (cm)	Mean x_1 (cm)
	Main scale (cm)	Vernier	Ver.× L.C. (cm)	Total (cm)	Main scale (cm)	Vernier	Ver.× L.C. (cm)	Total (cm)		
1										
2										
3										

Other End

No. of obs.	Right end Reading				Left end Reading				Diff. (cm)	Mean x_2 (cm)
	Main scale (cm)	Vernier	Ver.× L C. (cm)	Total (cm)	Main scale (cm)	Vernier	Ver.× L.C. (cm)	Total (cm)		
1										
2										
3										

Total elongation $= x_1 + x_2 = x = (l_2 - l_1)$ cm
$= \ldots\ldots\ldots$cm.

$$\therefore \qquad \alpha = \frac{l_2 - l_1}{l_1(t_2 - t_1)} = \frac{x}{l_1(t_2 - t_1)} = \ldots\ldots\ldots \text{per °C.}$$

Result. $\alpha = \ldots$per °C.

Standard value = ...per °C.
% of error = ...

Precautions. (i) See that the water is sufficient in the boiler.

(ii) In order to avoid back-lash error the microscope should always be made to move outwards in setting the cross-wires on the scratch.

(iii) Take care that the arrangement is not disturbed in any way after taking the initial reading of the microscope and allowing the steam to pass into the metal tube.

(iv) The rubber tube used to connect the boiler with side tubes P_1 and P_2 should be small so that condensation of steam may be small.

(v) The inlet pipes should be so connected that they gradually slope down from the boiler to the inlet ends.

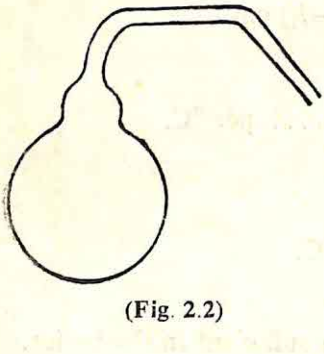
(vi) In such laboratories where travelling microscopes are not available, use should be made of microscopes having micrometer scales in eye-piece in place of travelling microscope.

COEFFICIENT OF CUBICAL EXPANSION OF LIQUIDS

EXPERIMENT. 2. **Determination of the co-efficient of expansion of a liquid by weight thermometer.**

Apparatus. Weight thermometer, (glycerine, aniline etc.), wire gauge, copper vessel, porcelain basin, ordinary thermometer, clamp, stand, balance, weight-box, burner.

Description of the apparatus : WEIGHT THERMOMETER. The wt. thermometer consists of spherical or cylindrical glass bulb, having a narrow neck drawn out at one end into a fine capillary with thick walls and generally bent twice so that its open end projects in a downward direction. Care is taken to see that the thickness of wall of the thermometer is uniform everywhere during the process of preparing it. If the bottom of the thermometer is thick due to collection of glass, there is probability of the bulb to crack while filling it with a liquid. The bulb is completely filled by the



(Fig. 2.2)

process of alternate heating and cooling method as done in the case of preparing a mercury thermometer. The experimenter has to take special care in handling this apparatus otherwise the capillary tube may break and lead to collapse of the experiment.

Theory. Let m_1 and m_2 be the masses of the given liquid which fill the wt. thermometer completely at temperatures t_1°C and t_2°C respectively.

Let d_1 and d_2 be the densities of the said liquid at temperatures t_1°C and t_2°C respectively and v_1 and v_2 their volumes at the temperatures t_1°C and t_2C°.

If γ_r be co-efficient of real expansion of liquid, and g the co-efficient of cubical expansion of vessel, then

$$\frac{m_1}{m_2}=\frac{v_1 d_2}{v_2 d_2}=\frac{v_1 d_2\{1+\gamma_r(t_2-t_1)\}}{v_2 d_2\{1+g\ (t_2-t)\}}$$

or
$$\frac{m_1}{m_2}=\frac{1+\gamma_r(t_2-t_1)}{1+g(t_2-t_1)}$$

or
$$m_2+m_2\gamma_r(t_2-t_1)=m_1+m_1 g(t_2-t_1)$$

or
$$m_2\gamma_r(t_2-t_1)=m_1-m_2+m_1 g(t_2-t_1)$$

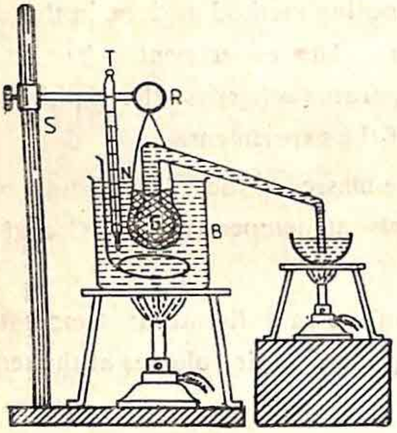
$$\therefore\quad \gamma_r=\frac{m_1-m_2}{m_2(t_2-t_1)}+\frac{m_1}{m_2}g$$

Thus the co-efficient of real expansion of liquid can be calculated if the co-efficient of expansion of vessels is known.

The quantity $\frac{m_1}{m_2}$ of Eqn. (1) is very nearly equal to unity and g is small compared to γ_r.

$$\therefore\quad \gamma_r=\frac{m_1-m_2}{m_2(t_2-t_1)}+g \qquad ..\ (2)$$

i.e. $\gamma_r=\dfrac{\text{mass expelled}}{\text{mass remaining}\times\text{rise of temp.}}$ + coefficient of cubical expansion of vessel .. (3)



(Fig. 2.3)

Procedure. (i) Prepare a wt. thermometer carefully and weigh it to the nearest milligram when it is clean, dry and empty. Let *m* be the mass of empty wt. thermometer. Then place it in a wire cage and suspend it from a ring *R* clamped to a stand *S*.

Take a porcelain crucible or basin and pour some experimental liquid, like aniline or glycerine in it. Now place it on a tripod stand of such a height that the end of the wt. thermometer may dip into the liquid. Now heat slowly the liquid and bulb both with bunsen flame. Some air is expelled from the bulb and if the burner below the bulb is removed, the bulb would consequently get cooled as a result of which some hot liquid from basin would flow into the bulb. Again heat the bulb and by the repeated heating and cooling process fill the bulb completely with the experimental liquid.

(ii) Allow the liquid in the wt. thermometer to cool down to the room temp. with its capillary end dipping into the experimental liquid. Fill the copper vessel *B* with water at room temperature such that the whole of the bulb and a part of its stem may be completely immersed. This would serve the purpose of bath. Place a stirrer in water bath.

(iii) Suspend a mercury glass thermometer in the bath near the bulb *G*. The temp. of the bath would initially appear to be slightly less than the room temp. Hence, increase the temperature of the bath slightly above the room temperature. Stir the bath constantly and keep the temperature of the bath stationary for at least five minutes by alternately placing the bunsen flame below the bath and removing it. The thermometer T records the steady temperature t_1°C of the bath.

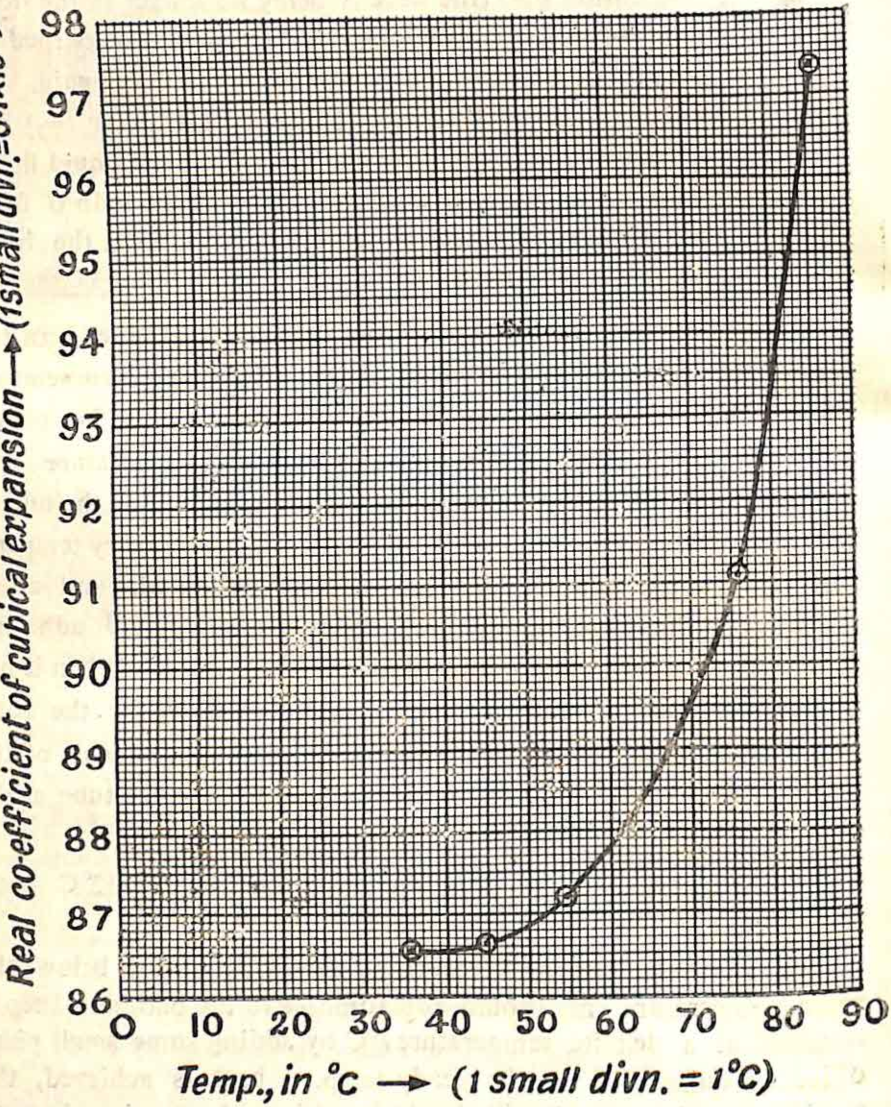
(iv) The bulb G is now taken out of the water bath by holding it by the suspension wire (the neck N being no longer in the liquid of vessel B) and any water on the outer surface should be wiped out by a clean cloth or blotting paper. Weigh it carefully again. Let w_1 be the total mass. The difference between this mass (w_1) and the mass of empty bulb (w) gives the mass m_1 of the liquid filling the bulb at room temperature t_1°C. After removing the bulb G from the bath, hold it away at the neck otherwise the heat from the body may heat it and consequently liquid may come out

(v) Again, place the bulb in the wire cage and introduce it in the water bath of vessel B as previously done. Raise the temperature of water bath to a definite temperature t_2°C which should be nearly 12°C above the temperature t_1°C. Keep this temperature t_2°C stationary at least for five minutes by placing or removing the burner below the bath as discussed above. Record this stationary temperature, take out the bulb G by holding it by suspension wire and allow it to cool to the room temperature. Wipe out any liquid adhering to the surface of G by blotting paper or clean cloth. When it has cooled to room temperature weigh it again. Let w_2 be the total mass. Hence, the difference between this mass w_2 and mass of the empty bulb (w) gives the mass m_2 of the liquid filling the tube at the temperature t_2°C.

(vi) Continue taking observations in steps of nearly 12°C until the water in the bath boils.

(vii) If one is desirous of recording some observation below the room temperature, he should add some ice to the bath and keep it constant at a definite temperature t°C by adding some small piece of ice if required. When the steady temp. of bath is achieved, the crucible containing the liquid should be replaced by a weighed empty crucible. Remove the bulb G from the bath B. It will be seen that some of the liquid comes into the weighed crucible. Now, the mass of liquid filling the bulb at t°C is calculated by weighing the liquid and the crucible together.

(vii) Tabulate the readings in the tabular form and calculate the mean co-efficient of the expansion of liquid γ by the equation 3. Then, plot a graph between temperature along the x-axis and γ along



(Fig. 2.4)

the y-axis (see fig. 2.4). The graph will indicate the variation of the co-efficient of expansion with temperature.

Observations And Calculations

No. of obs.	Mass of empty bulb	Temp. t_1°C	Temp. t_2°C	Mean temp. $=\frac{t_1+t_2}{2}$	Mass of bulb+ mass of liquid at t_1°C	Mass of bulb+ mass of liquid at t_2°C	g/°C	Co-efficient of expansion γ_r/°C
1	2·511	31°C	40·2	35·6	8·1136	8·0706	·000025	$86{\cdot}57\times10^{-5}$
2	2·51	40·2	49·7	44·95	8·0706	8·0265	·000025	$86{\cdot}64\times10^{-5}$
3	2·52	49·7	59·5	54·6	8·0265	7·9811	·000025	$87{\cdot}20\times10^{-5}$
4	2·51	70·1	80·3	75·2	7·9342	7·8856	·000025	$91{\cdot}13\times10^{-5}$
5	2·51	80·3	90·3	85·3	7·8856	7·8351	·000025	$97{\cdot}36\times10^{-5}$

Precautions. (i) As a part of the stem of the bulb projects above the bath the temperature of the projecting stem will be below that of the bath and hence, some error would be introduced in the result. So, immerse as much of the bulb and stem in the water bath as possible.

(ii) Weighing should be done only when the bulb with liquid has acquired the room-temperature. *Preferably, weighing should be done by method of oscillation.*

(iii) One should be careful particularly in handling the wt. thermometer as the capillary tube may break and lead to collapse of the experiment.

(iv) Do not suspend the bulb by thread with which water of different amount at different temperature may stick and cause a change in weight. Hence, suspend the bulb by a bare thin wire.

(v) While using water as experimental liquid, immerse wt. thermometer in bath maintained at temperatures of 60°C or 65°C by thermostatic arrangement in order that the evaporation of water filling the wt. thermometer may be prevented. The wt. thermometer to be used should be preferably of a larger size so that the liquid expelled may be appreciable.

(vi) Weighing should be performed with a good balance as the accuracy of result would depend on the mass of liquid expelled and the mass remaining in the wt. thermometer.

Note. How to prepare a Weight Thermometer.

The preparation of a weight thermometer requires the following three steps, viz.,

(i) *Closing the end of the tube.* For this purpose, hold the end of a glass tube in a blow pipe flame. When the glass edge softens, push its walls together with a piece of waste-glass. Now heat the tube beyond this portion (the end) keeping the glass piece adhered to it. Rotate the tube and give, while heating, a little strain outwards on the glass piece fixed on the end when a narrow neck will be formed; keeping the heating continued, the neck is gradully closed. Now take out the glass end piece when the tube will be closed but the closed end will be of conical shape. Heat it strongly and taking it out of the flame, blow gently into the tube.

(ii) *Blowing the glass bulb.* This is successfully done by (a) heating the heavy mass of soft glass to a uniform temperature in the flame and by (b) managing for symmetrical air cooling after taking it outside the flame.

For this purpose, hold the tube, in the flame, with its closed end slightly higher than the open end, and heat a further length of the tube. When the glass thickens and the bore is reduced to about half, heat a further length of the tube, rotating it all the time. Now, remove it from the flame and lightly blow into it. Again, put it in the flame, heat a further length and again blow. By this method of alternate heating and blowing, obtain a pear-shaped mass of glass. Now, heat this pear-shaped collected mass of glass to red hot. Next remove the tube from the flame, rotate it for a few seconds slowly and then blow in it first gently and then strongly as the glass solidifies. While blowing, keep the tube, in continuous slow rotation, in the vertical position with the hot end downwards; the tube may show a tendency to bulge outwards. In that case hold the tube horizontally with the bulge turned downwards when the bulb of uniform thickness will result. In case, it is not of uniform thickness and of regular shape, put it in the flame supplying the gas fully when its size will reduce. When it collapses try to blow the bulb again.

(iii) *Drawing capillary neck.* Allow the bulb to cool and when it has cooled, heat near the neck of the bulb and draw a capillary. Bend the capillary twice at about right angles my means of lighted match-stick.

ASSOCIATED EXPERIMENTS

1. *Use a specific gravity bottle to determine the co-efficient of cubical expansion of the liquid.*

Hint. Clean and dry the specific gravity bottle, as explained earlier, and weigh it.

Fill the bottle completely with the liquid given. Put it in the wire cage suspended by means of wire from a clamp fixed to a stand. Immerse the bottle up to its neck in water bath maintained at a temperature slightly above the room temperature.

Now repeat the procedure described in the experiment for the determination of co-efficient of expansion of liquid by weight thermometer and enter the result in the table as instructed therein. Finally draw a curve showing the variation of co-efficient of expansion with temperature.

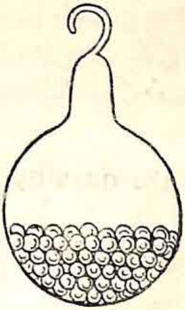
While working at temperatures above room temperature, every weighing should be made after wiping off the sides carefully and allowing it to cool. On the other hand, while working at temperatures below room temperature, some more liquid would be required and that should be introduced in the bottle through jet drawn at one end of the glass tube.

EXPERIMENT 3. **To determine the co-efficient of cubical expansion of a liquid at different temperatures using a glass bulb sinker.**

Apparatus. A glass sinker, balance, weight-box, thermometer, beaker, wooden bridge, heating and cooling arrangement, suspension arrangement for the sinker.

Description : GLASS SINKER. It consists of a completely closed glass bulb spherical or in cylindrical shape having a neck drawn out into a nozzle and formed into a hook as shown in the fig. 2.5. It can be easily suspended with the help of a fine silk fibre or horse hair or a very thin copper wire tied to its hook. Either some lead shots or some mercury is placed inside it to make it heavy so that it can sink ordinarily in water or a liquid.

Theory. According to Archemedes Principle, when a body is completely or partially immersed in a liquid it loses a part of its wt. and this apparent loss in wt. of body is equal to the wt. of liquid displaced.



(Fig. 2.5)

Let the true wt. of glass sinker in air be w (neglecting the buoyancy of air)

wt. ,, ,, ,, in liquid be w_1 at t_1°C

wt. ,, ,, ,, in liquid be w_2 at t_2°C where $t_2 > t_1$.

$\therefore$ Loss in wt. of sinker at $t_1°\text{C} = (w - w_1)$ .. (1),

,, ,, ,, ,, ,, ,, at $t_2°\text{C} = (w - w_2)$ .. (2).

Let V_1c c be the volume of glass sinker at the room temp. t_1C, and

V_2c c be the volume of glass-sinker at the temp. t_2°C.

Hence the volume of liquid displaced at temp. $t_1°\text{C} = V_1$ c c and the volume of liquid displaced at the temp. $t_2°\text{C} = V_2$ cc.

Let d_1 be the density of liquid at t_1°C, d_2 be the density of liquid at t_2°C.

$\therefore$ Wt. of liquid displaced at $t_1°\text{C} = V_1 d_1 = (w - w_1)$ .. (3).

,, ,, ,, ,, ,, $t_2°\text{C} = V_2 d_2 = (w - w_2)$ .. (4),

Dividing (3) by (4),

$$\frac{V_1 d_1}{V_2 d_2} = \frac{w - w_1}{w - w_2} = \frac{V_1 d_2\{1 + \gamma_r(t_2 - t_1)\}}{V_1 d_2\{1 + g(t_2 - t_1)\}}$$

$$= \frac{1 + \gamma_r(t_2 - t_1)}{1 + g(t_2 - t_1)},$$

where g is the co-efficient of cubical expansion of gases, and γ_r is the co-efficient of real expansion of liquid.

$$\therefore \quad \{w - w_1\}\{1 + g(t_2 - t_1)\} = (w - w_2)\{1 + \gamma_r(t_2 - t_1)\}$$

$$\therefore \quad (w - w_2) + (w - w_2)\gamma_r(t_2 - t_1) = (w - w_1) + (w - w_2)g(t_2 - t_1)$$

$$\therefore \quad (w - w_2)\gamma_r(t_2 - t_1) = (w - w_1 - w + w_2) + (w - w_1)g(t_2 - t_1)$$

$$= (w_2 - w_1) + (w - w_1)g(t_2 - t_1)$$

$$\therefore \quad \gamma_r = \frac{w_2 - w_1}{(w - w_2)(t_2 - t_1)} = \frac{w - w_1}{w - w_2} g \quad .. \quad (5)$$

As the quantity $\frac{w - w_1}{w - w_2}$ of Eq. (5) is very nearly equal to unity and is small compared to γ_r, hence

$$\gamma_r = \frac{w_2 - w_1}{(w - w_2)\,(t_2 - t_1)} + g \quad .. \quad (6).$$

In order to determine the apparent co-efficient of expansion of liquid the co-efficient of glass g can be dropped,

so that
$$Ya = \frac{w_2 - w_1}{(w - w_2)(t_2 - t_1)} \quad \ldots \quad (7).$$

Procedure. (i) Place a wooden bridge across the left pan of the balance so that it may not touch the pan or the frame of the pan. On this bridge place a beaker filled nearly three-fourths with experimental liquid. Let the glass-sinker be immersed wholly without touching any portion of beaker in liquid. The level of liquid in beaker should be such that the sinker may not come out when the beam is raised. Insert the bulb of a thermometer of suitable length in the experimental liquid in the beaker.

(ii) Note the temperature of liquid t_1°C stirring it well.

(iii) Place weights on the right pan to restore the equilibrium and note the wt. w_1 of the sinker when it is completely immersed in the liquid at t_1°C.

(iv) Remove the beaker with experimental liquid from inside the balance case. Heat the liquid in beaker till its temp. is about 50°C. In this case the temp. of the liquid should not be raised more than nearly 25°C above the room temp. as the convection current would be too heavy and the balance would be disturbed. Then quickly, place the beaker again on the bridge carefully. Determine its weight w_2 and note the temp. t_2°C of liquid at the moment when the balance is restored.

It is difficult to maintain the temp. of the liquid constant while weighing the sinker immersed in liquid by usual method. For the sake of convenience adjust the weights on the pan so that the sinker is found to be just a little heavier. (As the temp. is falling, density of liquid would increase, thereby the upward thrust would increase. Hence loss in wt. would increase.)

Consequently, after a few seconds the pointer of the balance passes through the zero position. Note the temp. say t_2°C just at this moment. Thus, the weights on the scale pan give the wt. of the sinker at that temp. t_2C.

(v) The temp. of the liquid will continue to fall. Wait till the temp. of the liquid has fallen about by 3°C nearly below the temp.

t_2°C. Reduce some weights on the pan and adjust the balance so that the sinker is again found to be a little heavier. After a few seconds, the pointer of the balance passes through the zero position. Note the temp. t_3°C of the liquid just at this moment when the pointer passes through zero position. Thus, the weights on the scale pan give the wt. of the sinker at temp. t_3°C. See that the temp. t_3°C is preferably 5°C below t_2C.

(vi) Go on taking readings at the interval of 5°C (proceeding as in operation 4 or 5) till room temperature is attained.

(vi) For taking some readings at the temperature below the room temp. add some ice to the bath not to the liquid if it is not water, till the temp. of liquid has lowered by about 5°C. Adjust the weights on the right pan till the sinker is found to be a bit lighter. As the temperature goes on raising, after a few seconds, the pointer of the balance passes through the zero position. Note the temperature of the liquid just at this moment. Thus, the weights on the scale give the wt. of sinker at that temp. As the temperature rises slowly the wt. of sinker at different temperatures can be found in a way as described above. Tabulate the readings as shown in the table.

Tabulate the result and calculate γ_r taking the value of g, the co-efficient of cubical expansion of glass to be 0·000025.

Plot the variation of γ_r (y-axis) with temp. (x-axis) on the graph paper.

No. of obs.	Wt. of the bulb w	Temperature of the liquid	Wt. of the bulb in liquid at different temperatures	$\gamma_r = \frac{w_2 - w_1}{(w - w_1)(t_2 - t_1)} + g.$
1		$t_1 =$	w_1	
2		$t_2 =$	w_2	
3				
...				
10				

Precautions. (i) With the help of a small camel hair brush, remove all the air bubbles sticking to the wall of sinker. Liquid, to be free from air dissolved in, should be preferably boiled and then cooled.

(ii) Suspend the bulb of the thermometer in the liquid as close to the sinker as possible. See that the bulb of the themometer may not touch the wall of sinker.

(iii) The suspension fibre should not be of cotton. The suspension fibre or wire should be so thin that the effects due to its surface tension may not be appreciable if it enters the liquid.

(iv) To achieve greater accuracy the correction should be made for the liquid displaced by the silk fibre or wire and lower portion of the wire should be a fine platinum wire so that the effect due to surface tension may be lowered.

(v) Before taking any observation, stir the liquid well. When the currents inside the liquid have subsided, note the reading of the thermometer as well as weights on the pan. It may be remembered that during actual weighing operation the sinker itself acts as a stirrer.

(vi) When the liquid in beaker is placed inside the balance its temperature should not be more than 25°C above or below the room temp., otherwise the balance would be disturbed due to the convection current. For extending the range further use a hydrostatic balance in which the suspension fibre is hooked to the pan of the balance and passes freely through the hole in the balance.

(vii) The sinker should be heavy and of sufficiently large size. Due to this the loss in weight would be appreciable and hence the error in the loss would be minimised.

VARIATION OF DENSITY OF A LIQUID WITH TEMPERATURE

EXPERIMENT 4. **Measurement of the variation in the density of a liquid (water) with change of temperature by weighted bulb.**

Apparatus. Weight thermometer, liquid (water or glycerine), wire gauge, copper vessel, porcelain basin, ordinary mercury thermometer (100°C), clamp, stand, balance, weight-box, burner.

Theory. Let m_1 and m_2 be the masses of the liquid which fill the wt. thermometer completely at temperatures t_1°C and t_2°C.

Let d_1 and d_2 be the densities of the same liquid (water).

Then,
$$\frac{m_1}{m_2}=\frac{V_1d_1}{V_2d_2}=\frac{V_1d_1}{V_1\{1+g(t_2-t_1)\}d_2} \quad .. \quad (1)$$

where g is the co-efficient of cubical expansion of glass.

(It should be remembered that a hollow vessel expands just as if it were a solid vessel of the same volume and material.)

or
$$m_2d_1=m_1\{1+g(t_2-t_1)\}d_2.$$

∴
$$d_2=\frac{m_2}{m_1}\cdot\frac{d_1}{\{1+g(t_2-t_1)\}}$$

or
$$d_2=\frac{w-w_1}{w-w_1}\times\frac{d_1}{\{1+g(t_2-t_1)\}} \quad .. \quad (3)$$

where w = mass of bottle with liquid in air and w_1 and w_2 are the masses of bottle in water at t_1°C and t_2°C respectively.

Thus, after knowing the masses of liquid filling the wt. thermometer at different temperatures, the density of the liquid at the room temp. and the co-efficient of cubical expansion of glass, density of the liquid at any temperature can be calculated.

Procedure. Proceed and take precautions as discussed in expt. with wt. thermometer. Use the formula given above and calculate the density of the liquid at different temperatures. Then plot a graph between temperature along the x-axis and density along the y-axis. (fig. 2.6). The curve so obtained will show the variation of density with temperature.

Note. If the experimental liquid is water, then, before filling the wt. thermometer with this liquid, boil the water thoroughly so that the air bubbles, if any present in it, may escape. Obtain the value of d_1 the density of water at room temperature from the table.

If the table is not available, then determine experimentally the mass of water at 4°C. The density of water at 4°C is unity. So, the equation (2) could be modified as

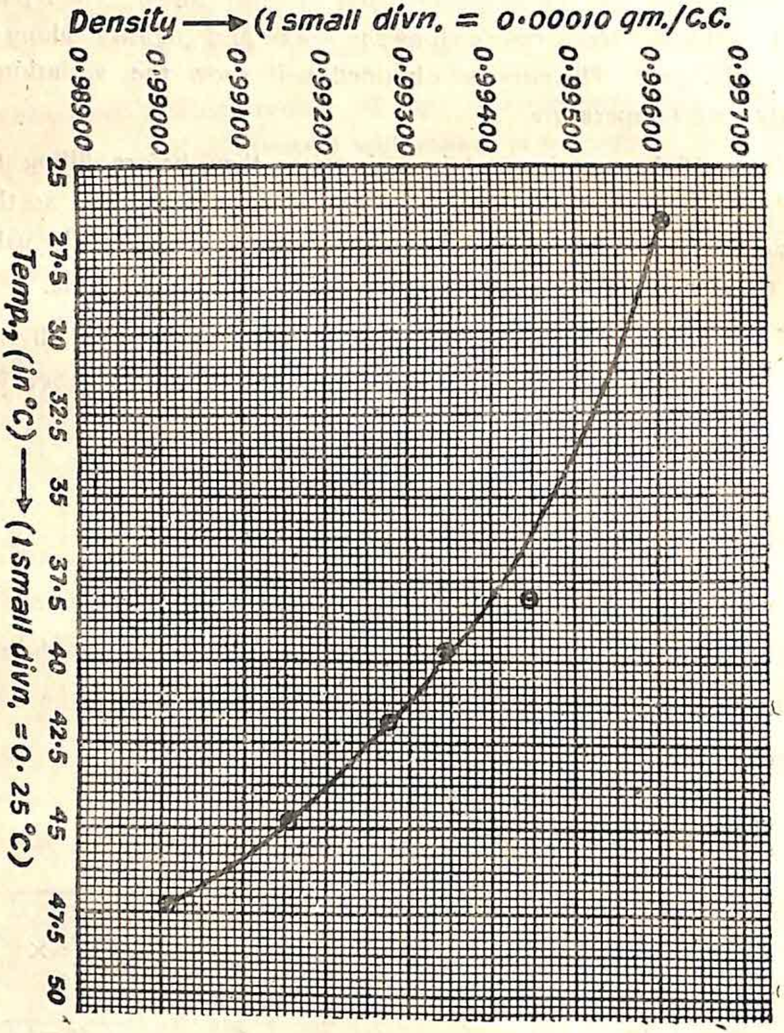
$$d_2=\frac{m_2}{m_1}\cdot\frac{1}{1+g(t_2-t_1)}.$$

The density at 2°C and 6°C is 0·99997 gm/cc which can be taken to be equal to unity for practical purposes. If there is difficulty in maintaining the bath at 4°C, maintain the bath between 2°C and 4°C and determine the mass of water.

Observations And Calculations

No. of obs.	Temp. of water in °C	Mass w gm. in air	Mass in gm in water	t_2-t_1 in °C	$w-w_1$ in gm.	$w-w_2$ in gm.	$d_2=\frac{w-w_2}{w-w_1}\times\frac{d_1}{1+g(t_2-t_1)}$ gm/cc
1	26·6 $=(t_1)$	139·520	89·505 $=w_1$	...	...	...	0·99603
2	47·2 $=t_2$	139·520	89·780 $=w_2$	20·6	50·015	49·740	0·99007
3	44.8	139·520	89·710	18·2	50·015	49·810	0·99151
4	41·8	139·520	89·650	15·2	50·015	49·870	0·99274
5	39·6	139·520	89·620	13·0	50·015	49·900	0·99342
6	38·0	139·520	89·570	11·4	50·015	49·950	0·99447

Precautions. Same as discussed in Expt. 2.



(Fig. 2.6)

ASSOCIATED EXPERIMENTS

1. *Determine the density of the given Liquid at three different temperatures at intervals of 10°C using a specific gravity bottle.*

Hint. Procceed in the same way as described for the determination of co-efficient of cubical expansion of liquid by specific gravity bottle.

Here, take the difference of temperature equal to 10°C. Finally, calculate the density at each temperature using the relation (2).

2. *Determine the density of water at three different temperatures at intervals of 10°C using glass bulb sinker.*

Hint. Proceed in the same way as described for the determination of co-efficient of cubical expansion by glass bulb sinker. Here take the difference of temperature equal to 10°C. Finally calculate the density at each temperature using the relation (3).

RADIATION CORRECTION

If temp. of calorimeter is higher than that of its surrounding it loses heat in three ways, (i) conduction, (ii) convection, (iii) radiation. The loss of heat by conduction is minimised by placing the calorimeter either on insulator, as cotton, wool or cork or by surrounding the calorimeter with these materials. A superior method of minimising the loss by conduction is either to suspend the calorimeter with strings inside a wooden box packed with cotton or wool or to place it on the strips of cardboard set on edge or by properly legging the calorimeter with an enclosed air layer.

Loss of heat due to convection is reduced by placing the calorimeter in an outer vessel having a wooden lid. The lid possesses two holes through which pass a thermometer and a stirrer in the calorimeter. The loss of heat due to conduction or convection is then minimised with these arrangements but not properly eliminated.

The surface of calorimeters are polished to minimise the loss of heat due to radiation as polishing reduces the emissivity of the surface. But the loss of heat due to radiation cannot be avoided easily because even if the calorimeter is placed in vacuum the radiation loss will continue in the usual way provided the temperature of calorimeter is higher than the temp. of surrounding. That is, the maximum loss of heat is due to radiation.

Secondly, when a body at a higher temp. than that of surrounding is dropped in the liquid of a calorimeter maintained at room temp. certain amount of heat is lost by it in transit by way of conduction, convection and radiation. So the final temp. attained by mixture would be less than what it would have been had there been of heat. Correction for such loss of heat in calorimeter expt. is known as radiation correction. Thus, the final temp. of mixture has got to be corrected for such loss of heat by radiation.

METHOD FOR RADIATION CORRECTION

Regnault's method. There are several methods to determine the loss of heat due to radiation but Regnault's method is more common due to its certain advantages.

Take a calorimeter and place it properly. Pour some liquid in it filling $\frac{1}{3}$ of its volume. Insert a sensitive thermometer reading $\frac{1}{10}$th of degree C in the liquid in calorimeter. Fix it to the vertical stand attached to the wall of the wooden vessel in which the calorimeter has been placed. Leave it for two to three minutes. Then, note the reading of the thermometer at interval of every half minute for three minutes, stirring the liquid all the time, with stop-watch. The temperature of the liquid will be found to be constant. Consider it to be the first part of the experiment.

Just after the end of the first part of the experiment (as referred) take a hot solid and allow it to fall in the liquid of calorimeter taking care that no liquid is splashed. As the solid enters the liquid the temp. of the liquid goes on rising. Note the reading of the thermometer at interval of every half minute till the maximum temp. of liquid is attained. Consider this portion of the experiment as the second part. Go on taking the reading of the thermometer for the next 8 to 10 minutes. This will be a period of fall of temperature. Consider this period of experiment as the third part. In case the body is a bad conductor of heat this period should be extended beyond 8 to 10 minutes and the reading of the thermometer should be noted preferably at the interval of 1 or 2 minutes. Record the observation in the tabular form as shown in Table 1, page 141.

The experimentor is advised to come prepared with a table on practical note book to record the readings of the thermometer in tabular form during the calorimetric experiments for radiation correction, otherwise it would be difficult for him to record the observation in the tabular form while stirring the liquid well and reading the temp. of thermometer carefully at definite intervals. The thermometer should be sensitive to read up to $\frac{1}{10}$th of a degree and $\frac{1}{100}$ degree applying eye-estimation.

TABLE 1

	1 Time in min.	2 Temp. of liquid in calorimeter in °C	3 Mean temp. during half minute interval in °C	4 Cooling during the interval from cooling curve in °C	5 Total cooling at the end of the interval in °C	6 Corrected temp. in °C	7 Mean corrected maxm. temp. in °C
I	0	21·35					
	½	21·35					
	1	21·35					
	1½	21·35					
	2	21·35					
	2½	21·35					
	3	21·35					
	3½	21·35					
Temp. rising II			Hot solid	dropped			
	4	29·00	25·17	0·0245	0·0245	29·024	
	4½	29·80	29·40	0·0525	0·0770	29·877	
	5	30·50	30·15	0·0573	0·1343	30·634	
	5½	30·70	30·60	0·0595	0·1938	30·894	
	6	30·80	30·75	0·0612	0·2550	31·055	31·32
	6½	31·00	30·90	0·0620	0·3170	31·317	
Temp. falling III	7	30·90	30·95	0·0625	0·3795	31·279	
	7½	30·85	30·88	0·0620	0·4415	31·291	
	8	30·80(a)	30·83	0·0615	0·5030	31·303	
	8½	30·75(b)	30·78	0·0612	0·5642	31·314(M)	
	9	30·70(c)	30·73	0·0610	0·6252	31·325	
	9½	30·65(d)	30·68	0·0608	0·6860	31·336	
	10	30·60(e)	30·63	0·0605	0·7465	31·346	
	10½	30·50(f)	30·55	0·0598	0·8063	31·306	
	11	30·45(g)	30·48	0·0595	0·8658	31·316	
	11½	30·40(h)	30·43	0·0590	0·9248	31·325	
	12	30·35(i)	30·38	0·0588	0·9836	31·334	
	12½	30·30(j)	30·33	0·0580	1·0416	31·342	
	13	30·25	30·28	0·0580	1·0996	31·349(N)	

(i) Find the mean temperature during each of the half minute interval by taking the mean of the temperatures preceding and succeeding the interval and note it in column (3) of table (1). As for example 251·7°C is the mean of 29·00°C and its previous temperature (before the interval) 21·35°C. Similarly 29·40°C is the mean of 29·80°C and its previous temp. (before the interval) 29·00°C and so on.

(ii) Select the reading in column (2) a little after the temperature begins to fall and mark them as (a), (b), (c), (d), etc. Find out the time interval that elapes between (a)th and (f)th reading, (b)th and (g)th reading and so on, which would be equal to $2\frac{1}{2}$ minutes according to the experiment. Then find out the cooling in °C between the (a)th and (f)th, (b)th and (g)th and so on as shown in the table II, which would stand for time $2\frac{1}{2}$ minutes. Tabulate them properly and take their mean which would be mean cooling for $2\frac{1}{2}$ minutes. Hence find out the cooling for $\frac{1}{2}$ minute corresponding to the mean temp. $t' = \frac{a+b+c\ldots\ldots+j}{10}$.

TABLE II

To find rate of cooling

Interval of two and half minutes	Cooling of the temperature in °C	Cooling for $2\frac{1}{2}$ mins. in °C	Average cooling for $\frac{1}{2}$ minute in °C	Mean of ten falling temp. i.e. $\frac{a+b+\ldots\ldots+j}{10}=t'$
From (a)th to (f)th min.	From 30·80 to 30·50	0·30		$\overset{(a)}{30\cdot80}+\overset{(b)}{30\cdot75}+\overset{(c)}{30\cdot70}+\overset{(d)}{30\cdot65}$
From (b)th to (g)th min.	From 30·75 to 30·45	0·30		$+\overset{(e)}{30\cdot60}+\overset{(f)}{30\cdot50}+\overset{(g)}{30\cdot45}$
From (c)th to (h)th min.	From 30·70 to 30·40	0·30	$\frac{0\cdot30}{5}$	$\dfrac{+\overset{(h)}{30\cdot40}+\overset{(i)}{30\cdot35}+\overset{(j)}{30\cdot30}}{10}$
From (d)th to (i)th min.	From 30·65 to 30·35	0·30	$=0\cdot06$	$=30\cdot55°C=t'$.
From (e)th to (j)th min.	From 30·60 to 30·30	0·30		

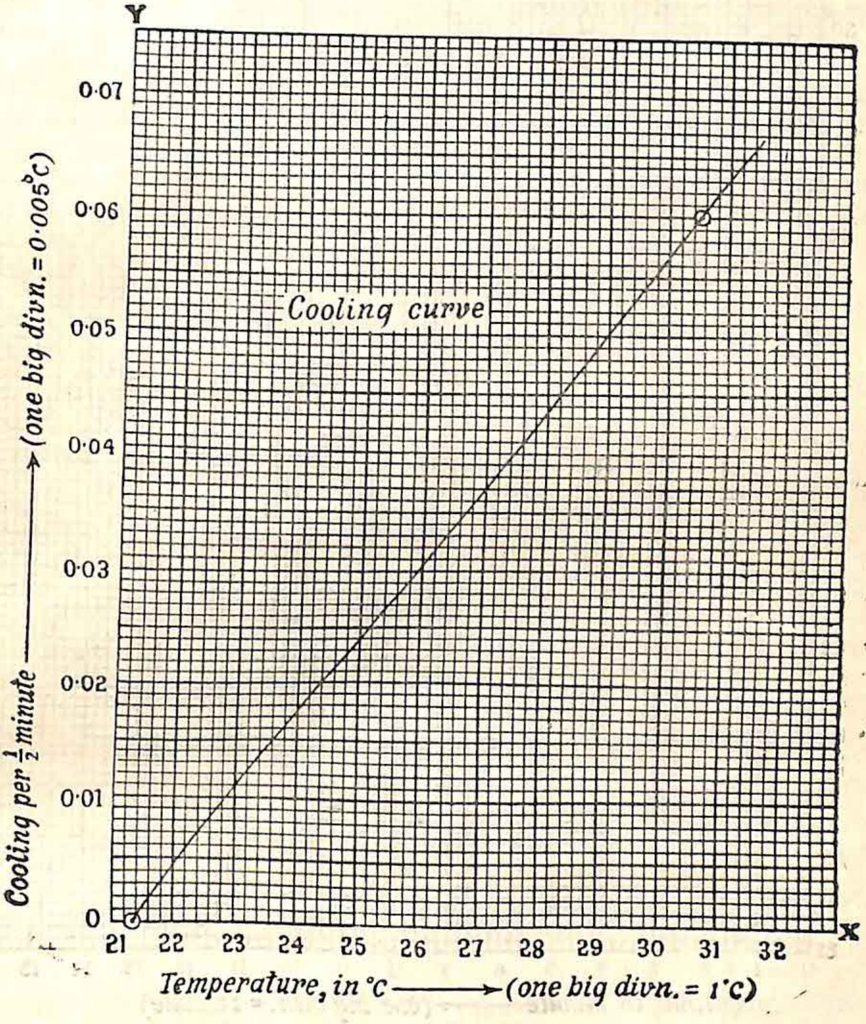
The temp. t in the first part of experiment i.e., room temp. is found to be constant and hence the rate of cooling at this constant room temp. is zero.

Thus, rate of cooling at room temp. $21\cdot35=0$ (zero) and rate of cooling for $\frac{1}{2}$ minute at the mean of the ten falling temp. 30·55°C $=0\cdot06$°C.

Now plot a cooling curve taking mean temperature along x-axis and cooling per half minute along y-axis with these two data. A st. line would result when these two points are joined.

From this straight line curve, cooling for any definite mean temp. is found.

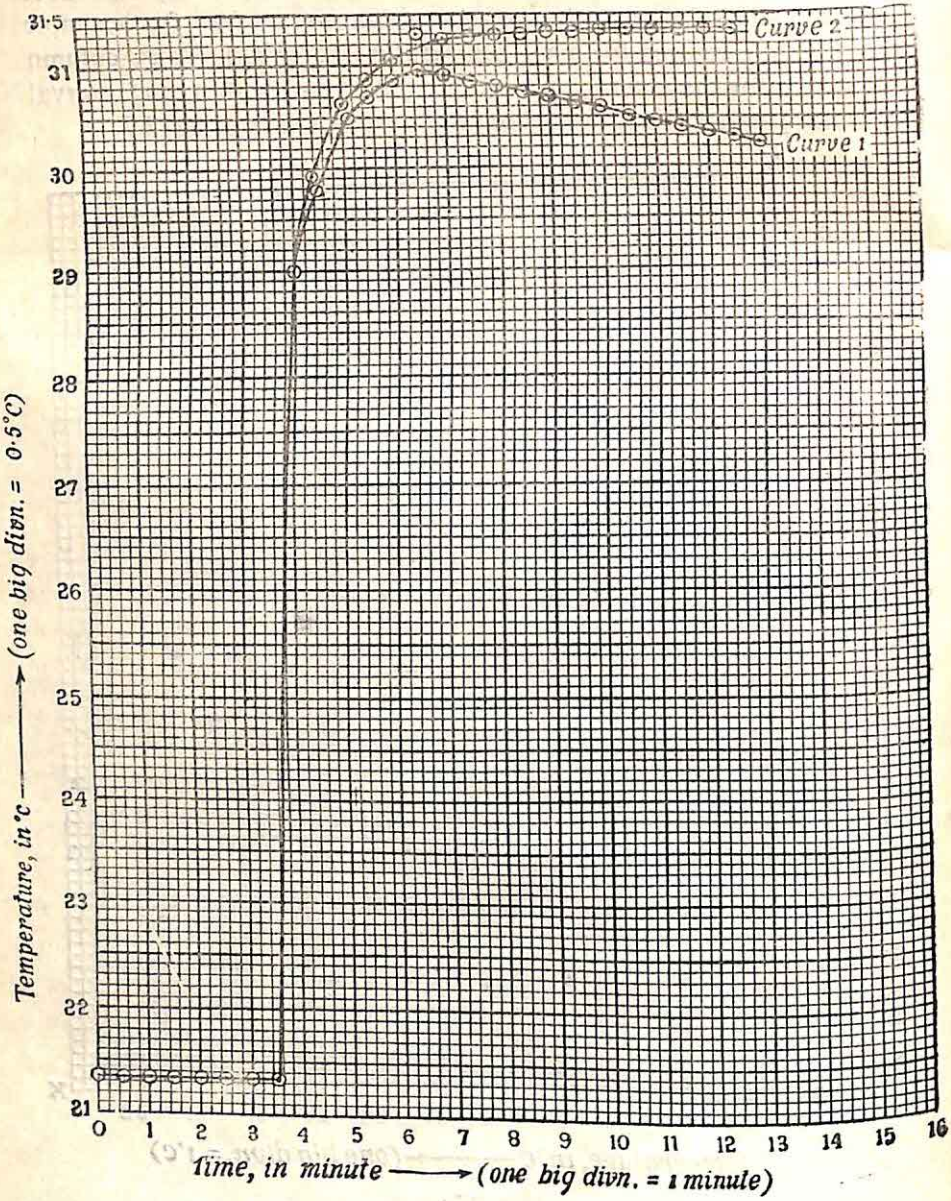
From the graph (fig. 2·5) read the value of rate of cooling corresponding to temperatures in column (3) of table (1) and note it by the side of that mean temp. on column (4). (As for example 0·0245 is the cooling for mean temperature 25·17°C.) Thus, column (4) stands for the cooling at a mean temperature within an interval of time ($\frac{1}{2}$ min.) as obtained from the cooling curve of fig. 2.7.



(Fig. 2.7)

Now, find out the total cool ing at a mean temperature. For this, proceed as follows—

The cooling at a mean temperature must be added to the sum of the coolings occurring at all the mean temperatures previous to this to give the total cooling at the mean temperature. The following example will make it clear. Say, the total cooling at the

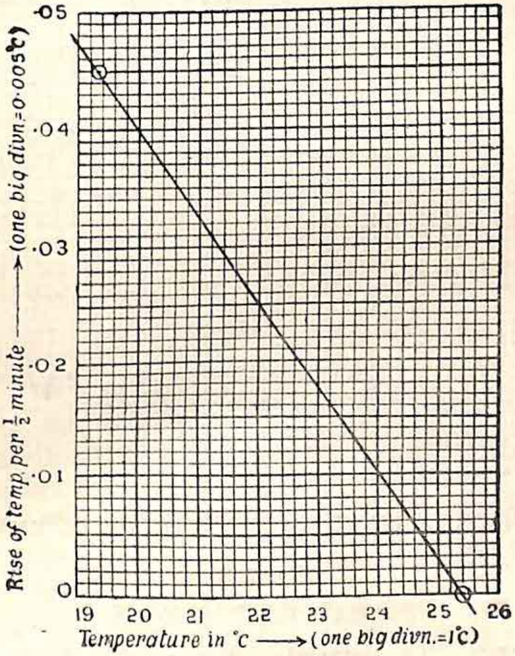


(Fig. 2.8)

mean temp. 30·60°C = 0·0595 + (sum of all the previous coolings) i.e. 0·0595 + (0·245 + ·0525 + ·0573) = 0·1938°C. Enter them properly in column (5) of table (I). Thus column (5) stands for total amount of cooling at the mean temperature.

To find the corrected temp. at any particular time, add to the temperature at that time the total cooling which has taken place before that temperature. (Example : corrected temp. at the 9th minute = 30·70 + total cooling at that time = 30·70 + 0·6252 = 31·325°C.) Calculate them as mentioned above and record them in column (6) of the table (I). Now draw a graph with uncorrected temperatures on *y*-axis and time on *x*-axis (fig. 2.6, curve 1). Then, draw a graph taking the corrected temp. on the *y*-axis and time on the *x*-axis on the same time-temp. graph (fig. 2.6, curve 2). The end portion of the corrected temperature graph would be parallel to the time axis. This shows that the calorimeter would have attained this maximum corrected temp. had there been no loss of heat. The maximum temp. attained is obtained by taking the mean of the corrected temperatures lying between *M* and *N* in column (6) of table (I).

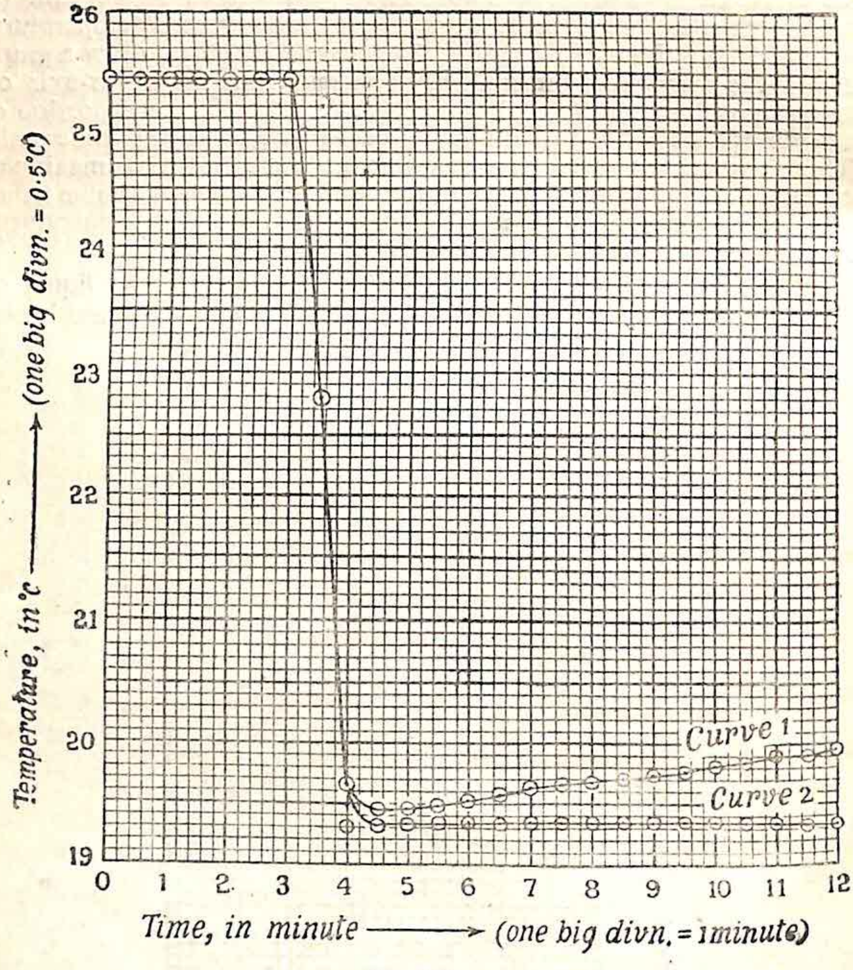
If a cold body (such as ice) is introduced into the liquid of the calorimeter, instead of a hot body then the temp. of calorimeter would first begin to fall and attain a minimum value.



(Fig. 2.7)

After this the temperature of the calorimeter would begin to rise instead of falling (during the third part of expt.) because the temperature of surrounding is higher than the temperature of calorimeter in this case. Here, the calorimeter would gain heat instead of suffering loss during this part of experiment. Record the time and temperature and hence calculate the temp. per half minute due to gain of heat and adopt the procedure discussed above to determine the correction for gain of heat.

In this case, the time temperature graph would be as shown below (see. Fig. 2.7 and Fig. 2.8).



(Fig. 2.8)

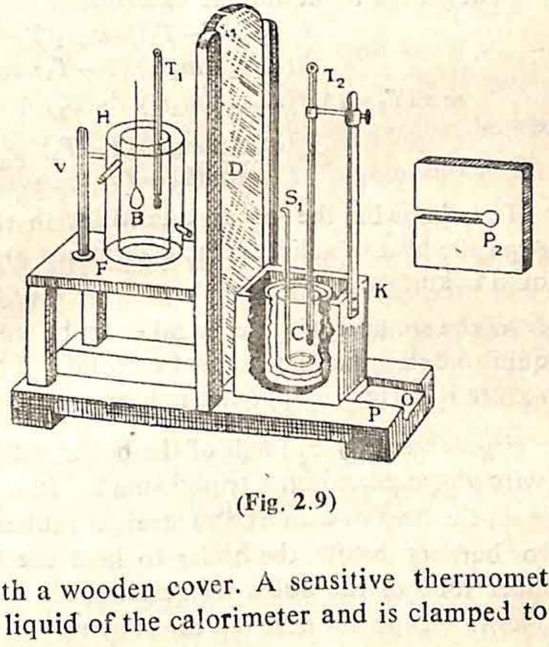
SPECIFIC HEAT

EXPERIMENT 5. **To determine the specific heat of a solid by Regnault's apparatus applying radiation correction.**

Apparatus. Regnault's apparatus, solid, calorimeter and stirrer, thread, balance and weight-box, heater—Bunsen burner and two thermometers (one 100°C and other 50°C), stop-watch.

Description of the apparatus : REGNAULT'S APPARATUS. Regnault's apparatus (shown in fig. 2.9) consists of a steam heater *H* on a platform and a calorimeter *C*, thermally screened from each other by means of a vertical wooden shutter *D* which can slide up and down in the grooves of its frame.

The steam-heater made of two co-axial cylinders having an annular space between them is carefully closed except for the two outlets for the entrance and exit of steam. The mouth of inner cylinder is closed with a cork having two holes through which pass a thermometer T_1 and a string carrying the solid *B* at one of its ends. The solid to be heated is suspended by means of a string in the interior of the inner chamber and the bulb of thermometer T_1 is also placed in the interior of inner chamber close to the solid to record its correct temperature. Steam is allowed to pass through the annular space and interior of the inner cylinder acts as oven for the solid to be heated. The bottom of the inner cylinder is closed by a trap door through which the solid may be dropped in the calorimeter. The steam heater is hinged to a vertical rod *V* fixed to the raised platform *F* having central hole.



(Fig. 2.9)

Calorimeter is placed in a copper vessel separated from each other with non-conducting material. Calorimeter *C* is made of copper. It is polished and supported on pointed pieces of wood or by means of strings inside the wooden box. The box is packed with cotton-wool. It is provided with a wooden cover. A sensitive thermometer T_2 is inserted in the liquid of the calorimeter and is clamped to a vertical rod. The calorimeter has a stirrer placed inside the liquid.

Theory. Specific heat of a body at any temp. is defined as the amount of heat required to raise the temperature of the body through any range of temperature to the amount of heat required to raise the temp. of same mass of water through the same range of temp. According to this definition, specific heat has no unit.

It is also defined as the amount of heat in calories required to raise the temp. of 1 gm of a body by 1°C. Specific heat is determined by the method of mixture.

Let m_1 = mass of the calorimeter and the stirrer,
s_1 = sp. heat of material of calorimeter,
m_2 = mass of liquid in calorimeter,
s_2 = specific heat of the liquid,
T_1 = initial temp. of the liquid in the calorimeter,
m = mass of the heated solid,
s = specific heat of material of the solid,
T_2 = temp. of the heated solid,
T = final common temp. of the calorimeter, its contents and the solid.

Then, heat lost by solid $= m.s.(T_2-T)$ .. (1).

Heat gained by liquid and calorimeter

$$= m_2s_2\,(T-T_1)+m_1s_1(T-T_1)$$

$$= (m_2s_2+m_1s_1)\,(T-T_1) \text{ cal.} \qquad .. \ (2).$$

$$m.s.(T_2-T) = (m_2s_2+m_1s_1)(T-T_1)$$

$$s = \frac{(m_2s_2+m_1s_1)\,(T-T_1)}{m(T_2-T_1)} \text{ cal.} \qquad .. \ (3).$$

Thus knowing the other quantities in the eqn. (3), the value of specific heat of solid can be determined provided the sp. heat of liquid is known.

As the sp. heat of water is taken to be unity, water is taken as a liquid to determine the sp. heat of solid. The maximum temp. T of mixture is corrected applying radiation correction.

Procedure. (i) Fill half of the boiler with water and place it on a wire guage placed on a tripod stand. Join it to the inlet of jacket S with the help of a short and straight rubber tube. Apply one or two burners below the boiler to heat the water. Connect a long rubber tube to the outlet of heater to allow the steam coming from boiler to escape not near the calorimeter.

(ii) Examine the different parts of Regnault's apparatus and see whether the shutter and calorimeter slide in the grooves engraved for them in the frame of apparatus according to necessity.

The box of calorimeter should be free to solid and come below the central hole of the platform so that the slide can be lowered down into the calorimeter without obstruction.

(iii) While the water in the boiler is being heated weigh the solid in a balance. Let its mass be m gm. Tie it with a string and then suspend it in the interior of the inner cylinder of the jacket H. Close the upper mouth of the interior of cylinder of jacket H with a cork having a hole through which passes a 100°C mercury thermometer such that its bulb is either in contact with solid or close to it to record its correct temp. See that the cork is tightly fitting. The lower end of the jacket is closed with metal trap-door. Turn the jacket away from the central hole in the platform.

(iv) While the solid is being heated in the jacket, take out the calorimeter with its stirrer from the wooden box, clean it, dry it and weigh it correct up to a centigram. Let m_1 gm be the mass of calorimeter with stirrer. Fill half of calorimeter with water so that the solid may dip completely in it when allowed to fall. Weigh the calorimeter together with water. The difference between these two weights will give the mass of water. Let m_2 gm be the mass of water.

(v) Now replace the calorimeter with the liquid in the wooden box in which it is suspended by means of fine strings from the rim of the outer copper vessel. Insert the bulb of a sensitive thermometer (0–50°C) reading $\frac{1}{10}$ of a degree centigrade in the liquid of calorimeter. Close the mouth of calorimeter with wooden lid and see that the shutter has been lowered down in order that calorimeter and its contents may remain unaffected from the heat of the heating-chamber.

(vi) Wait and watch if the reading of the thermometer in the heater H (jacket) is steady at least for ten minuts in case of good conductor of heat (and nearly 40 minutes in case of bad conductor of heat).

(vii) Rotate the jacket H about hinge so that it is just above the central hole in the platform. Stir the water well and start the stop-watch and note its temperature every half minute when five or six readings have been taken. Raise the shutter quickly and bring the wooden box containing the calorimeter just below the hole. Quickly remove the trap door from the bottom of the jacket and drop the heated solid directly into the calorimeter by unying the string quickly and carefully so that no water splashes out of calorimeter. Remove the calorimeter quickly to its former position and lower the shutter also to its former position. Stir the water well and go on taking readings of temperature at every half minute till ten minutes have elapsed after the maximum temperature has been attained as in the experiment described for radiation correction.

(viii) The temp. of liquid in the calorimeter should be notde after an interval of half a minute beginning from at least five consecutive intervals before the hot solid is dropped in the liquid.

(ix) Now, find out the temp. corrected for loss of heat dut to radiation as described in expt. for radiation correction. Let the corrected temp. be T°C. Then calculate the sp. heat of the solid.

Observations and Calculations

Weight of calorimeter + stirrer = m_1 gm.

„ „ „ + „ + water = w gm.

Weight of water = $(w-m) = m_2$ gm.

Wt. of solid = m gm.

Initial temp. of water = T_1°C.

Temp. of solid = T_2°C.

Sp. heat of material of calorimeter = s_1 = ·09 (given).

Sp. heat of water = $s_2 = 1$.

$$s=\frac{(m_2s_2+m_1s_1)\,(T-T_1)}{m\,(T_2-T)}.$$

Standard value of $s=\ldots\ldots$

% of error..........

Equation (3) for determination of the sp. heat of solid can also be used to determine the sp. heat of a liquid provided the sp. heat of solid is given.

Precautions. (i) Solid should be dropped quickly in the calorimeter so that the loss of heat during the transference may be minimum.

(ii) The size of solid should not be too small.

(iii) It is advisable to use magnifying glass to observe the rapidly falling temperature from the thermometer. Record the temp. carefully to the second place of decimal.

(iv) The quantity of water in the calorimeter should be sufficient to immerse the solid completely.

(v) Before removing the thermometer from the liquid of the calorimeter, see that there is no trace of the liquid sticking to the bulb or the wall of thermometer.

(vi) The two thermometers used should be compared.

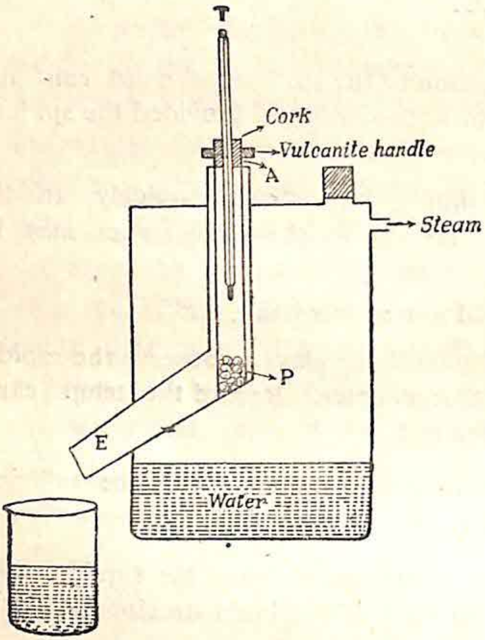
ASSOCIATED EXPERIMENTS

1. *Determine the temperature of the Bunsen flame by using a metal ball and a calorimeter, correcting for heat loss due to radiation.*

Hint. Take a solid of known specific heat and heat it in the given Bunsen flame, whose temperature is to be determined, for a pretty long time so that the solid attains the temperature of the flame.

Now, taking this as the hot solid, repeat the experiment for the determination of specific heat of solid by Regnault's apparatus. Apply the radiation correction for obtaining the final temperature of the mixture and hence, calculate the temperature of the hot solid, since its specific heat is known. This will give the temperature of the Bunsen flame corrected for radiation loss.

2. *Determine accurately the specific heat of the given badly conducting solid.*



(Fig. 2.10)

Hint. For the purpose of determining the specific heat of badly conducting solid, either Indian rubber, glass or lead shots may be supplied. In case of rubber, cut it into very thin pieces and tie them in a bundle. Heat this bundle in the heater, for a pretty long time so that it attains the temperature of the steam.

In case of small lead shots or broken glass pieces, where it is not possible to heat the body by suspending it by means of thread in a heater, use the alternative method of heating as shown here. When the glass-pieces or the lead shots *P* acquire the temperature of the steam, raise the vessel *A* sot hat the solid will fall through the exit *E* into the calorimeter.

Follow the rest procedures similar to that described for the determination of specific heat of solid by Regnault's apparatus. Correct the temp. of the mixture for radiation loss and calculate the sp. heat of the given badly conducting solid, using the relations given therein.

3. *Determine accurately the specific heat of the given liquid by the method of mixture. A solid ball of a material of known specific heat will be provided.*

Hint. Repeat the experiment for the determination of specific heat of solid taking the given liquid, in place of water, in the calorimeter. Specific heat of solid being known, calculate the specific heat of the given liquid.

WATER EQUIVALENT OF CALORIMETER

EXPERIMENT 6. To determine the water equivalent of calorimeter and stirrer.

Apparatus. Calorimeter with stirrer, beaker, balance, stop watch, weight-box, two thermometers (one reading up to 100°C and other reading up to 50°C), magnifying glass, Bunsen burner etc.

Theory. Thermal capacity of a body is the quantity of heat required to raise the temperature of the whole of the body through 1°C. Then, if m be the mass of a body and s be its specific heat, the thermal capacity of the body $= m.s.$ .. (1)

The water-equivalent of a body is the mass of water in grams which can be heated through 1°C by the amount of heat which can heat the body through 1°C. Thus we see that the water equivalent of a body is numerically equal to the thermal capacity of the body.

If w be the water equivalent of a body, then $w = m.s.$ .. (2)

The experiment to determine the water equivalent of calorimeter is based on the method of mixture. In this case a known mass of hot water is poured on a known mass of water at room temperature contained in the known mass of a calorimeter. The heat lost by the hot water is equated to the heat gained by the calorimeter and the cold water and the water equivalent of the calorimeter is determined from this equation.

Let m_1 = mass of calorimeter + stirrer

w_1 = ,, ,, ,, + ,, + cold water at room temp.

Mass of cold water $= (w_1 - m_1) = m_2$.

t_1°C = temp. of cold water,

t_2°C = temp. of hot water,

t°C = temp. of mixture.

w_2 = mass of calorimeter + stirrer + cold water + hot water.

∴ Mass of hot water $= (w_2 - w_1) = m_3$.

Let w be the water equivalent of the calorimeter.

Heat lost by hot water $= m_3.1.(t_2 - t)$ cal. ... (3)

Heat gained by calorimeter + stirrer + cold water

$$= (w + m_2).1.(t - t_1) = (w + m_2)(t - t_1) \text{ cal.} \quad .. (4)$$

∴ Heat gained = Heat lost

or $$(w + m_2)(t - t_1) = m_3(t_2 - t),$$

∴ $$(w + m_2) = \frac{m_3(t_2 - t)}{(t - t_1)};$$

$$\therefore \qquad w=\frac{m_3(t_2-t)}{(t-t_1)}-m_2. \qquad \text{.. (5)}$$

The temp. t of mixture should be corrected for loss of heat due to radiation and then the value of w should be calculated knowing the other quantities in equation (5).

Procedure. (i) Clean the calorimeter and stirrer. Dry them and weigh them together. Let m_1 be their mass.

(ii) Fill one-third of the calorimeter with cold water so that bulb of sensitive thermometer may be immersed completely. Weigh the calorimeter together with stirrer and cold water. Determine the mass m_2 of cold water from the difference of these two weights.

(iii) Replace the calorimeter with stirrer in its wooden box so that no water splashes. Insert the bulb of a sensitive thermometer (0°-50°C) in the cold water so that it is completely immersed in the water of calorimeter. Stir the water well and note the temp. t_1°C of the cold water.

(iv) Take some water in a beaker. The volume of water taken in beaker should be nearly equal to the volume of water taken in calorimeter. Place it on a wire gauge placed on a tripod stand. Apply Bunsen burner below it. Insert the bulb of a thermometer (0°1-00°C) in the water of beaker. Wait and watch the rise of temp. of water. When the temp. of water in beaker is nearly 10°C above the room temperature, stir the cold water in calorimeter and take five or six readings at the interval of every half minute. Just after the last reading of cold water is noted, holding the beaker containing hot water with right hand and thermometer with left hand, record the temp. of hot water after stirring it a little with the thermometer and pour it in cold water in calorimeter quickly and cover the lid of calorimeter. Note the temp. of mixture at intervals of half a minute after the last reading of cold water has been recorded.

Continue to stir the mixture and go on taking reading of the temp. of the mixture every half minute. Continue taking readings for nearly ten minutes after the temp. of mixture begins to fall.

(v) Remove the cover from the top of the calorimeter and then remove the thermometer from the mixture taking care that no trace of water comes out sticking with the wall of thermometer. Take out the calorimeter with stirrer from the wooden box and weigh it again when it attained the room temp. The difference in the third and second weights would give the mass m_3 of the hot water.

(vi) Now, suspend the bulbs of ordinary thermometer and the sensitive thermometer in cold water and see whether both of them have the same temp. If the readings of both the thermometers are not the same, then note the readings of thermometers. Taking the reading of sensitive thermometer to be true, find their difference and add it to the temp. t_2°C of hot water for correction.

(vii) Calculate the corrected temp. t°C of mixture due to loss of heat applying the principle of radiation correction as discussed earlier and hence calculate the value of water equivalent w of calorimeter and stirrer.

TABLE I

Time-Temperature record

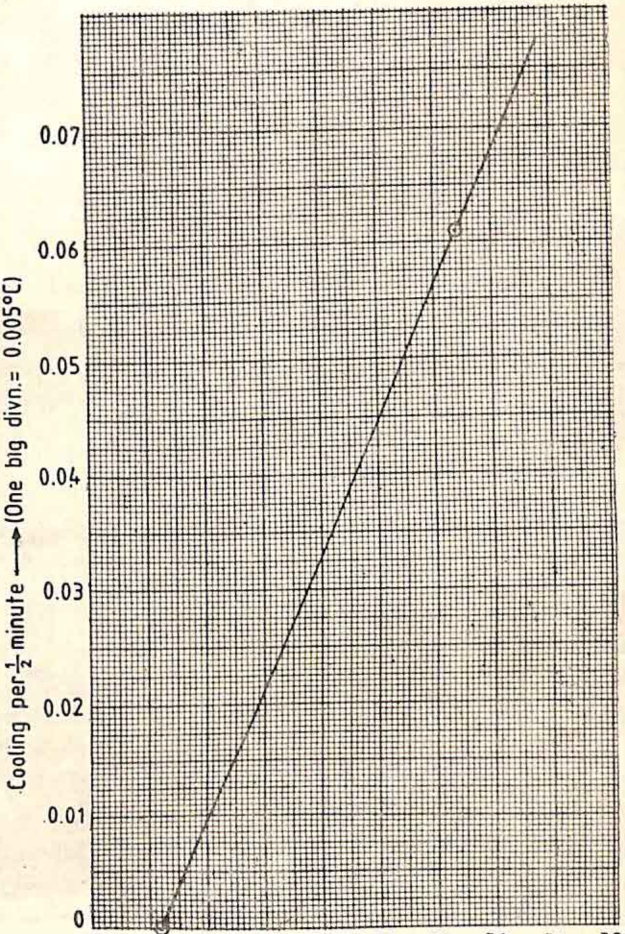
	1	2	3	4	5	6	7
	Time in min.	Temp. of liquid in calorimeter in (°C)	Mean temp. during half minute interval in (°C)	Cooling during the interval from cooling curve in (°C)	Total cooling at the end of the interval in (°C)	Corrected temp. in (°C)	Mean corrected maxm. temp. in (°C)
I	0	24·20	24·20	0			
	½	24·20	24·20	0			
	1	24·20	24·20	0			
	1½	24·20	24·20	0			
	2	24·20	24·20	0			
	2½	24·20	24·20	0			
	3	24·20	24·20	0			
Temp. rising II		Hot Water added					
	3½	29·78	26·89	0·0315	0·0315	29·811	
	4	30·25	30·02	0·0676	0·0991	30·349	
	4½	30·30	30·28	0·0705	0·1696	30·470	

	1	2	3	4	5	6	7
	Time in min.	Temp. of liquid in calorimeter in (°C)	Mean temp. during half minute interval in (°C)	Cooling during the interval from cooling curve in (°C)	Total cooling at the end of interval in (°C)	Corrected temp. in (°C)	Mean corrected maxm. temp. in (°C)
Temp. rising III	5	30·20	30·25	0·0700	0·2396	30·440	30·330
	5½	30·12	30·16	0·0692	0·3088	30·429	
	6	30·04	30·08	0·0685	0·3773	30·417	
	6½	29·95	30·00	0·0675	0·4448	30·395	
	7	29·86	29·90	0·0665	0·5113	30·371	
	7½	29·78	29·82	0·0655	0·5768	30·357	
	8	29·70 (a)	29·74	0·0645	0·6413	30·341(M)	
	8½	29·63 (b)	29·68	0·0638	0·7051	30·335	
	9	29·58 (c)	29·60	0·0630	0·7681	30·348	
	9½	29·50 (d)	29·53	0·0623	0·8304	30·330	
	10	29·48 (e)	29·46	0·0615	0·8919	30·322	
	10½	29·37 (f)	29·40	0·0608	0·9527	30·323	
	11	29·31 (g)	29·34	0·0600	1·0127	30·323	
	11½	29·25 (h)	29-28	0·0592	1·0719	30·322	
	12	29·20 (i)	29·22	0·0585	1·1304	30·330	
	12½	29·14 (j)	29·17	0·0580	1·1884	30·328(N)	
	13	29·09	29·12	0·0575	1·2459	30·336	
	13½	29·04	29·07	0·0570	1·3029	30·343	
	14	29·00	29·02	0·0565	1·3594	30·359	

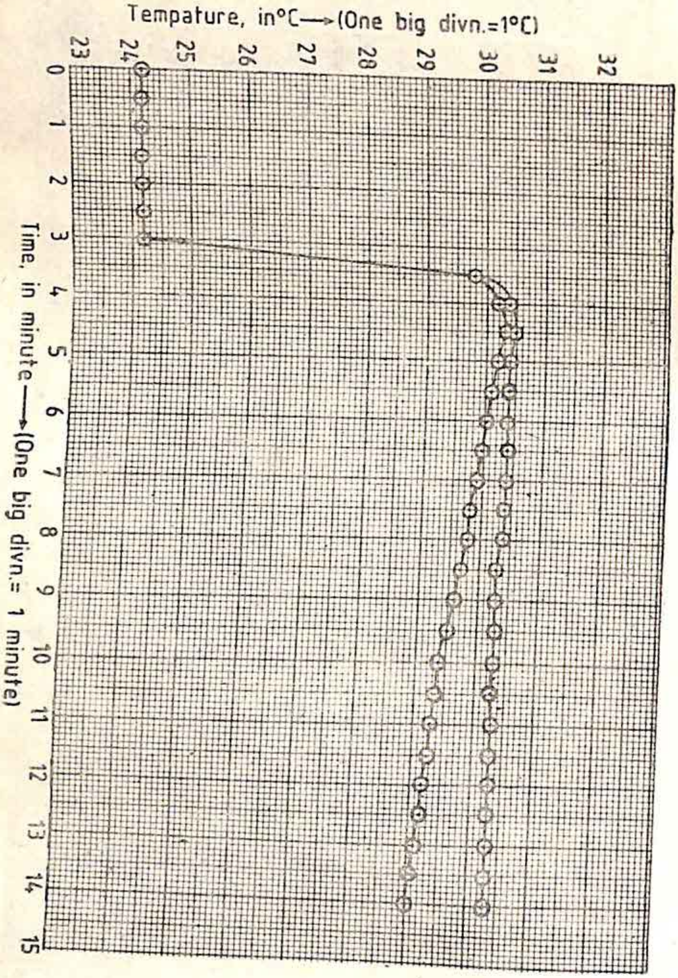
TABLE II

To find rate of cooling

Interval of 2½ minutes	Cooling of the temp. in (°C)	Cooling for 2½ minutes in (°C)	Average cooling for ½ minute in (°C)	Mean of ten falling *j* temp. i.e. $t'=\frac{a+b+\ldots}{10}$
From (a)th to (f)th reading	30·70 to 29·37	0·33	$\frac{0{\cdot}305}{5}$ =0·061	=29·41°*C*
From (b)th to (g)th reading	29·63 to 29·31	0·32		
From (c)th to (h)th reading	29·56 to 29·25	0·31		
From (d)th to (i)th reading	29·50 to 29·20	0·30		
From (e)th to (j)th reading	29·43 to 29·14	0·29		


0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Cooling per $\frac{1}{2}$ minute ⟶ (One big divn.= 0.005°C)
23
24
25
26
27
28
29
30
31
32
Temperature, in °C ⟶ (One big divn.= 1°C)

(Fig. 2.11)


Tempature, in°C⟶(One big divn.=1°C)
23
24
25
26
27
28
29
30
31
32
Time, in minute⟶(One big divn.= 1 minute)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

(Fig. 2.12)

Observations and Calculations

Corrected temp. of mixture $= t°\text{C} = 30{\cdot}33°\text{C}$.

Mass of (calorimeter+stirrer) $= m_1 = 65{\cdot}221$ gm.

Mass of calorimeter+stirrer+ cold water) $= w_1 = 145{\cdot}312$ gm.

∴ Mass of cold water $= (w_1 - m_1) = m_2 = 80{\cdot}091$ gm.

Temp. of cold water $= t°\text{C} = 24{\cdot}20°\text{C}$.

Temp. of hot water $= t_2°\text{C} = 36{\cdot}78°\text{C}$.

Mass of (calorimeter+stirrer+cold water+hot water) $= w_2 = 227{\cdot}332$ gm.

∴ Mass of hot water $= (w_2 + w_1) = m_3 = 82{\cdot}020$ gm.

Form formula (5), water equivalent (w)

$$= \frac{m_3(t_2 - t)}{(t - t_1)} - m_2$$

$$= \frac{82{\cdot}020\,(36{\cdot}78 - 30{\cdot}33)}{(30{\cdot}33 - 24{\cdot}20}$$

$$= 6{\cdot}210 \text{ gm.}$$

Value of w from formula (2) i.e. $w = m.s = 65{\cdot}221 \times 0{\cdot}094$

$$= 6{\cdot}131 \text{ gm.}$$

∴ % error $= 1{\cdot}29\%$ (for calorimeter of copper).

Result. Water equivalent (w) of calorimeter and stirrer from expt.

$$= 6{\cdot}210 \text{ gm.}$$

$$\% \text{ error} = 1{\cdot}29\%.$$

Precautions. (i) The temp. of hot water should not be more than 12°C higher than the room temp.

(ii) Calorimeter should be kept away from the heating arrangement.

(iii) The mouth of calorimeter should be always closed with cover.

(iv) The hot water should be transferred quickly and carefully to the cold water in the calorimeter so that water does not splash.

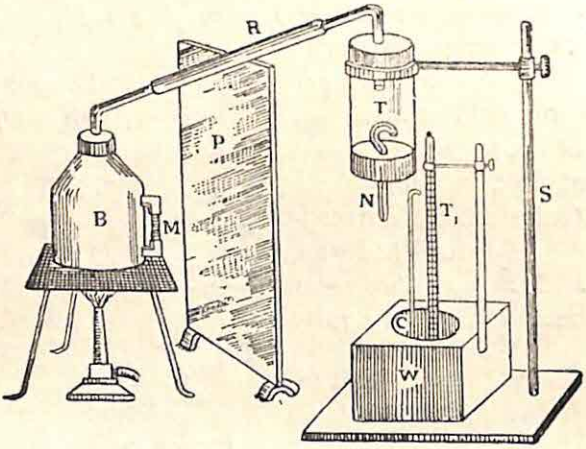
(v) Temp. of water should be recorded only when the water has been well stirred.

LATENT HEAT OF VAPORISATION

EXPERIMENT 7. To determine the latent heat of vaporisation of water applying radiation correction.

Apparatus. Calorimeter and stirrer, balance, weight-box, a sensitive thermometer (50°C), boiler, steam-trap, tripod-stand, wire-gauge, burner, screen, Fortin's barometer, stop-watch.

Description of the apparatus : STEAM TRAP. Steam-trap is a hollow



(Fig. 2.13)

cylindrical glass tube; its one end is closed with a cork having a hole through which passes the end of the glass tube bent at the top. The other end of this glass tube is joined to the outlet of boiler with the help of a rubber tube *R*. The other end of the steam trap also is closed with the help of tightly fitting cork having a hole through which passes a glass tube having a nozzle at its lower end and a sign of interrogation at the top.

Theory. The latent heat of vaporisation at the boiling point is defined as the amount of heat required to change 1 gm of water from its liquid state to vapour state without change of temperature.

The determination of latent heat of vaporisation is also based on the method of mixture where heat lost is equivalent to heat gained. Here, a definite quantity of steam is allowed to pass in a known quantity of water maintained at a particular temperature in calorimeter of known mass. The heat lost by the steam is equal to the heat gained by calorimeter plus water.

Let m_1 gm = mass of calorimeter + stirrer,
s_1 = specific heat of the calorimeter,
w_1 gm = mass of calorimeter + stirrer + cold water taken.
$\therefore$ Mass of cold water $= (w_1 - m_1) = m_2$ gm.
Temperature of cold water $= t_1$°C.
Temperature of steam $= t_2$°C.

Temperature of mixture after passing steam in it $= t$°C.

w_2 gm. = mass of calorimeter + stirrer + cold water + hot water.

$\therefore$ Mass of steam passed $= (w_2 - w_1) = m_3$ gm.

Let L cal./gm. be the latent heat of vaporisation of water.

$\therefore$ Heat lost by steam $= m_3L + m_3(t_2 - t)$ cal. .. (1)

$\therefore$ Heat gained by calorimeter + stirrer + water

$= (m_1s_1 + m_2)(t - t_1)$ cal. .. (2)

Now, Heat lost = Heat gained.

$$\therefore \quad m_3[L + (t_2 - t)] = (m_1s_1 + m_2)(t - t_1)$$

$$\therefore \quad L = \frac{(m_1s_1 + m_2)(t - t_1)}{m_3} - (t_2 - t) \text{ cal./gm.} \quad \text{.. (3)}$$

The temperature t°C of mixture has to be corrected as its observed value will be less than the corrected value due to loss of heat by radiation. Thus knowing the quantities concerned in equation (3), the value of L can be determined.

Procedure. (i) Fill nearly half of the boiler with water which would be indicated by a glass manometer attached to it. Place it on a wire gauge placed on a tripod-stand and keep Bunsen burner below it.

(ii) Close the mouth of the boiler with a cork lightly. Connect the upper end of the glass tube of steam trap to the outlet of boiler with a short rubber tube.

(iii) Take out the calorimeter and stirrer from the wooden box. Then clean, dry and weigh them together correctly in a balance. Let m_1 gm. be the mass of the calorimeter with stirrer. Fill one-third of the volume of calorimeter with cold water at room temperature and again weigh it. The difference in the two weights will give the mass of the cold water (m_2 gm.). Next place the calorimeter in the wooden box and cover it. Insert the bulb of a sensitive thermometer reading 1/10th of a degree, in the cold water of calorimeter through a hole in the covering lid and suspend it with the help of clamp fixed to a stand so that the bulb of thermometer may remain completely immersed in water and it may not touch the bottom or wall of calorimeter nor it may in any way obstruct the process of stirring.

(iv) In the meanwhile the steam would be issuing forth from the steam trap. Stir the water well in calorimeter and note its temperature at the interval of every half minute with the help of stop-watch. As soon as the last reading of cold water is taken, remove any trace of water sticking to the nozzle by means of cotton-wool and allow the steam to pass in the cold water instantaneously taking care that nozzle is a little below the surface of the water in the calorimeter. At the same time go on taking the reading of temperature of mixture at the interval of half minute after the last reading of cold water is noted. Stir the mixture well all the time and as soon as the temperature of mixture rises by 7 to 8°C, remove the steam trap and continue to take readings for 10 minutes more after the temperature of mixture begins to fall.

(v) Now, remove the thermometer from the water of calorimeter with no water sticking to it. When the water has attained the room temperature, weigh the calorimeter with its contents again and find out the mass (m_3 gm.) of steam condensed. Note the reading of the Fortin's barometer also.

(vi) Determine the maximum temperature (t°C) of the mixture applying the radiation correction as discussed earlier.

Calculate the temperature of steam from the following formula—

The B. P. of water at 760 mm. of pressure is 100°C.

∴ Due to change of 26·8 mm. of pressure the change in B P. is 1°C,

∴ ,, ,, ,, $\pm h$,, ,, ,, ,, $\pm \frac{1}{26 \cdot 8} \times h$°C

∴ B. P. of water at $(760 \pm h)$ mm. pressure

$$= 100 \pm \left(\frac{h}{26 \cdot 8} \right) {}^{\circ}\mathrm{C}$$

$$= t_2{}^{\circ}\mathrm{C} = \text{temp. of steam.}$$

(vii) Determine the latent heat of vaporisation of water with the given formula.

TABLE I

Time-Temp. Record

1	2	3	4	5	6	7
Time in min.	Temp. of water in calorimeter in °C	Mean temp. in °C during half minute interval	Cooling during the interval from cooling curve in °C	Total cooling at the end of the interval in °C	Corrected temp. in °C	Mean corrected maxm. temp. in °C
0	25 15					
½	25·15	25·15	0			
1	25·15	25·15	0			
1½	25·15	25·15	0			
2	25·15	25 15	0			
2½	25·15	25·15	0			
3	25·15	25 15	0			

	1	2	3	4	5	6	7
	Time in min.	Temp. of water in calorimeter in °C	Mean temp. in °C during half minute interval	Cooling during the interval from cooling curve in °C	Total cooling at the end of the interval in °C	Corrected temp. in °C	Mean corrected maxm. temp. in °C
Temp. rising II			Steam was allowed to pass				
	3½	28·55	26·85	0·0082	0·0082	28·558	
	4	31·65	30·10	0·0237	0·0319	31·682	
	4½	34·75	33·20	0·0385	0·0704	34·820	
	5	35·50	35·12	0·0480	0·1184	35·618	
Temp. falling III			Steam was stopped				
	5½	35·40	35·45	0·0495	0·1679	35·568	
	6	35·35	35·38	0·0492	0·2171	35·567	
	6½	35·30	35·33	0·0490	0·2661	35·566	
	7	35·25	35·28	0·0487	0·3138	35·564	
	7½	35·19	35·22	0·0484	0·3622	35·552	
	8	35·15	35·17	0·0482	0·4104	35·560	
	8½	35·10(a)	35·12	0·0480	0·4584	35·558 (M)	
	9	35·05(b)	35·08	0·0478	0·5062	35·556	35·553
	9½	35·00(c)	35·02	0·0475	0·5537	35·554	
	10	34·95(d)	34·93	0·0473	0·6010	35·551	
	10½	35·90(e)	34·92	0·0470	0·6480	35·548	
	11	34·86(f)	34·88	0·0468	0·6948	35·555	
	11½	34·81(g)	34·84	0·0465	0·7413	35·551	
	12	34·76(h)	34·78	0·0463	0·7876	35·548	
	12½	34·72(i)	34·74	0·0461	0·8337	35·554	
	13	34·68(j)	34·70	0·0458	0·8795	35·559(N)	

Interval of 2½ minutes	Cooling in temp. in °C	Cooling for 2½ minutes in °C	Average cooling for ½ min. in °C	Mean of ten falling temp. in °C
From (a)th to (f)th reading	35·10 to 34·86	0·24	$\frac{0·234}{5}$	
From (b)th to (g)th reading	35·05 to 34·81	0·24	=0·0468	$t' = \frac{a+b+\dots j}{10}$
From (c)th to (h)th reading	35·00 to 34·76	0·24		=34·88
From (d)th to (i)th reading	34·95 to 34·72	0·23		
From (e)th to (j)th reading	34·90 to 34·68	0·22		

Please see graphs 2.14 and 2 15.

Reading of barometer = 754·40 mm.

Boiling point of water at this pressure $= \left(100 - \frac{5{\cdot}6}{26{\cdot}8}\right)$°C = 99·79°C.

Observations and Calculations

Corrected maximum temp. of mixture, t_1°C = 35·55°C.

Mass of (calorimeter + stirrer) = m_1 = 165·265 gm.

Mass of (calorimeter + stirrer + cold water) = 500·770 gm.

∴ Mass of cold water = m_2 = 335·505 gm.

Temp. of cold water = t_1°C = 25·15°C.

Temp. of mixture = t°C = 35·55°C.

Mass of (calorimeter + stirrer + cold water + condensed water vapour) = 506·860 gm.

∴ Mass of condensed water vapour = m_3 = 6·090 gm.

Temp. of steam (by calculation) = t_2°C = 99·79°C.

∴ Latent heat of vaporisation = L = 535·24 cal./gm.

Standard value of Latent heat of vaporisation
= 539·60 cal./gm.

∴ %error = 0·81%.

Result. Latent heat of vaporisation of water = 535·24 cal./gm.
%error = 0·81%.

Precautions. (i) Follow all precautions discussed in calorimetric experiments.

(ii) The nozzle of steam trap should not be above the water surface otherwise there would be a great loss of heat.

(iii) The supply of steam should be regular and slow otherwise water may splash in calorimeter.

(iv) The calorimeter and boiler should be partitioned with a screen as shown in the fig. 2.13.

(v) Burner should not be removed from the boiler as long as the nozzle of steam trap is below the water surface.

LATENT HEAT OF FUSION OF ICE

EXPERIMENT 8. **Determination of the latent heat of fusion of ice.**

Apparatus. Calorimeter with stirrer (perforated disc type), stop watch, sensitive thermometer (reading up to 1/10th of a degree), balance, weight box, blotting paper etc.

Theory. When a solid substance is heated, its temperature rises, and at a constant pressure when it begins to melt, the temperature becomes constant and it remains constant so long as the whole of the substance does not melt. At the melting point, the amount of heat supplied to the substance is used up only in changing its state from solid to liquid. At a constant pressure, the amount of heat required to change unit mass of ice from solid to liquid state, at its melting point is defined as the Latent heat of fusion of ice.

The following experiment for the determination of latent heat of fusion of ice is based upon the method of mixture in which a known quantity of ice is added to a known quantity of water contained in a weighed calorimeter. Noting the final temperature of the mixture, thus produced, the amount of heat lost by the calorimeter and its contents and that of heat gained by the ice are equated and the latent heat of fusion of ice is calculated.

Let, the mass of the calorimeter+stirrer $= m$ gm.

Mass of the calorimeter+stirrer+water contained in it $= w$ gm.

$\therefore$ Mass of water taken $= (w-m)$ gm. $= m_1$ gm.

Initial temperature of water and calorimeter $= t_1$°C.

Final (corrected) temperature of the mixture after adding the ice $= t$°C.

Temperature of the ice $= t_2$°C ($=$ 0°C).

Mass of the calorimeter+stirrer+water taken+ice added $= w_1$ gm.

$\therefore$ Mass of ice taken $= (w_1 - w)$ gm.

$= m_2$ gm.

Also, let latent heat of fusion of ice $= L$ cal./gm.

So, the amount of heat required to melt m_2 gm. of ice is $m_2 L$ cal. and that required to raise its temperature from 0°C to the temp. of the mixture $= m_2 .\ 1.\ (t-0) = m_2 t$ cal. Also, amount of heat lost by the calorimeter and its contents

$$= m.s.(t_1 - t) + m_1(t_1 - t)$$
$$= (ms + m_1)(t_1 - t) \text{ cal.}$$

where s is the sp. heat of the material of calorimeter and stirrer.

Since, heat gained = heat lost,

$$\therefore \quad m_2 L + m_2 t = (ms + m_1)(t_1 - t)$$

$$\therefore \quad L = \frac{(ms+m_1)(t_1 - t)}{m_2} - t \text{ cal./gm.}$$

Other quantities being known, L can be evaluated.

Procedure. (i) First perform the preliminary experiment to know whether the dew point is near the room temperature or far below it. For that purpose, proceed as follows.

(ii) Take a clean, dry calorimeter and along with the stirrer of perforated disc type, weigh it correct up to a centigram.

(ii) Fill nearly two-thirds of the calorimeter with tap water. Note its temperature. Add some ice to it so that its temperature falls by 5 to 7°C. See whether dew has appeared on the outer surface of the calorimeter. If not, continue adding some more ice, observing the appearance of dew all the time, till the temperature falls by 10°C. If the dew has appeared during this operation, note the temperature at which this happens. If not, the dew point is still lower and hence its knowledge is not required for the present purpose. In the latter case, adopt method A and in the former case, adopt method B given below, for the determination of latent heat of fusion of ice.

METHOD A

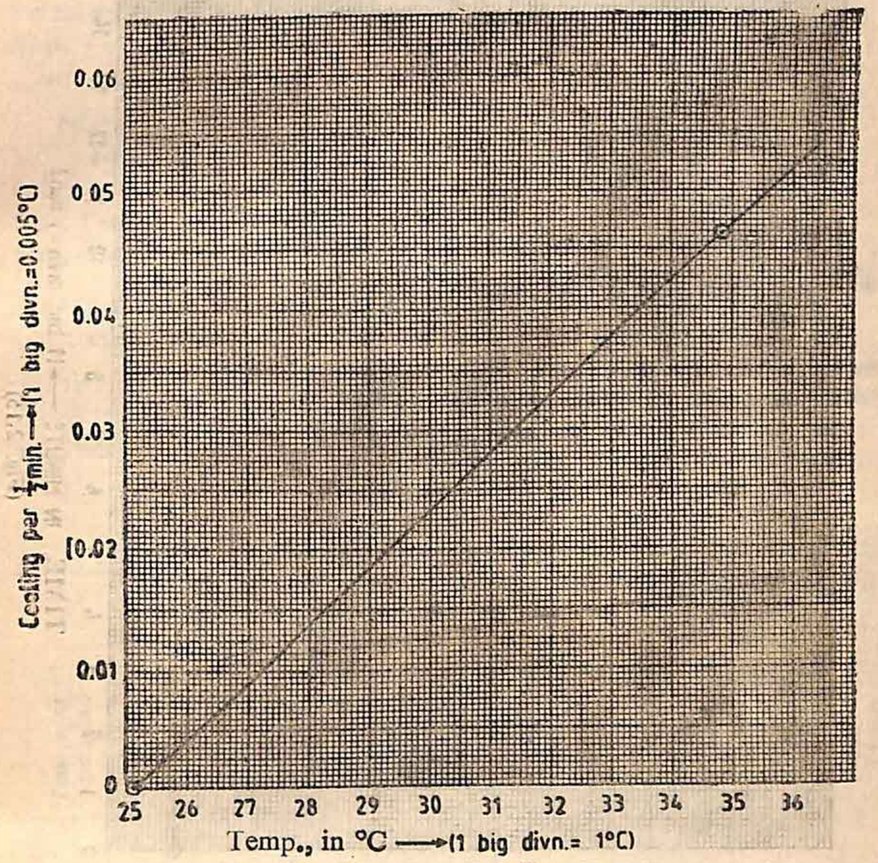
In seasons, when the atmosphere is relatively dry and dew point is not reached for a fall of temperature by about 10°C, proceed as follow for determining the latent heat of fusion of ice.

(i) Take the calorimeter which was weighed previously. Fill nearly two thirds of the calorimeter with tap water and weigh it again. The difference of the two weights will give the mass of water taken in the calorimeter.

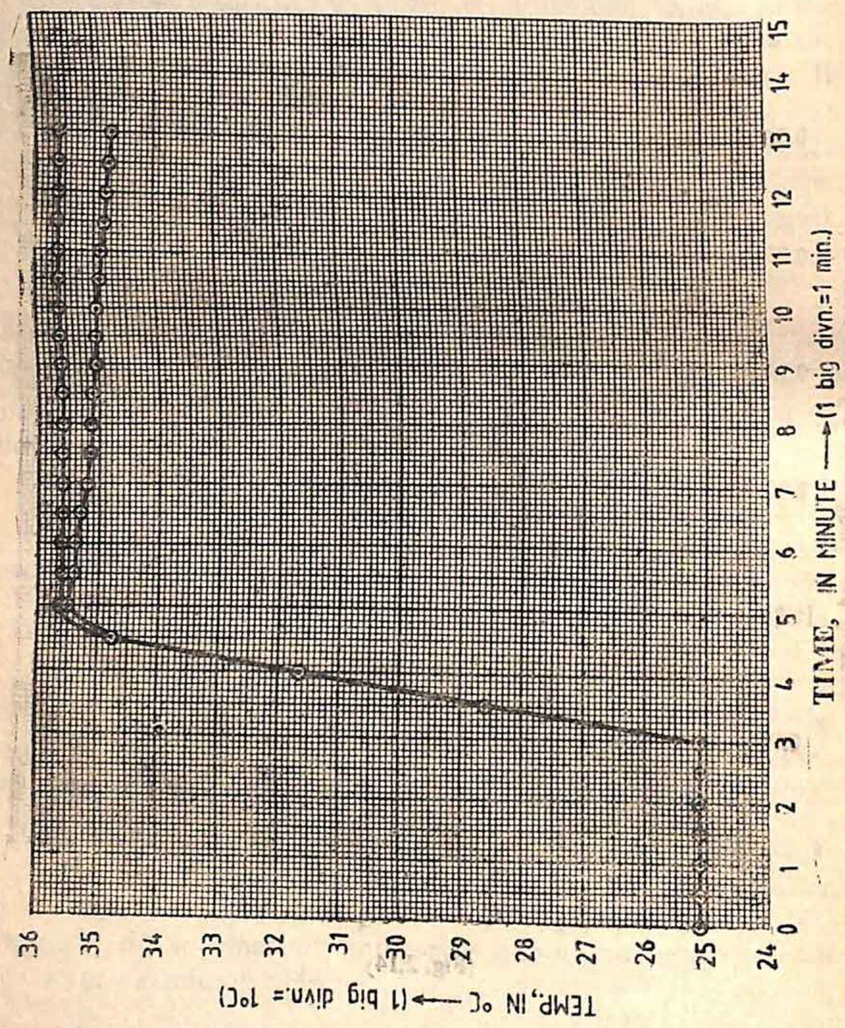
(ii) Place the calorimeter in its box. Fix the sensitive thermometer with its bulb well inside the water in the calorimeter. Cover it with the lid. Stirring well, note the temperature of water for 3 minutes at an interval of 30 sec. each. This will be practically constant.

(iii) From the knowledge of the preliminary experiment, take such a lump of ice which when added to the water in the calorimeter, would reduce its temperature by 7 to 8°C. With the help of blotting paper, dry it completely and gently drop it into the water. Note this instant when ice is added.

(iv) Keeping the lump of ice always under the perforated disc stirrer and stirring the water well all the time, continue to note the temperature at an interval of half a minute. The temperature will first fall and will begin to rise again. Take a good number of readings, say up to an interval of ten minutes after the record of the minimum temperature.


0.06
0.05
0.04
0.03
0.02
0.01
0
25
26
27
28
29
30
31
32
33
34
35
36
Cooling per $\frac{1}{2}$ min. ⟶ (1 big divn.=0.005°C)
Temp., in °C ⟶ (1 big divn.= 1°C)

(Fig. 2.14)


TEMP, IN °C ⟶ (1 big divn.= 1°C)
24
25
26
27
28
29
30
31
32
33
34
35
36
TIME, IN MINUTE ⟶ (1 big divn.=1 min.)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

(Fig. 2.15)

(v) Take out the thermometer carefully so that no water remains adhered to its bulb. Take out the calorimeter from its box and weigh it again. The difference of the third and the second weights will give the mass of ice taken.

(vi) Enter your results in the table given below. The heating at the room temperature is zero. From the observation, calculate the average heating at a particular mean temperature. From these two draw a heating curve (in place of cooling curve, as in other experiments on calorimetry) which should be a straight line. (See fig. 2.7)

(vii) From the heating curve, find out the heating for each interval. Total heating up to the end of a particular interval, when subtracted (and not added, as in other experiments on calorimetry) from the temperature at the end of that interval will give the correct temperature.

(viii) Draw the time-temperature (observed) and time-temperature (corrected) graphs. (See fig. 2.8)

(ix) From a set of corrected temperatures, calculate the mean corrected temperature. Finally, with the knowledge of mean corrected minimum temperature, calculate the value of L.

Observations

I	II	III	IV	V	VI	VII	VIII
Time-interval (in min.)	Temp. at the beginning of interval (°C)	Temp. at the end of interval (°C) (a)	Mean temp. during the interval (°C)	Heating during the interval (°C)	Total heating up to the end of interval (°C) (b)	Corrected temp. (°C) $a-b$	Mean corrected temp. (°C)
0-0·5							
0·5-1·0							
1·0-1·5							
Ice added							
12-12·5							
12·5-13·0							

METHOD B

During the rainy season, when the atmosphere is quite moist, the dew point is only a few degree centigrade below the room temperature. Hence a fall of temperature of the calorimeter and its contents by 5 to 7°C, caused by the additions of ice into the water, contained in the calorimeter, may produce a deposit of dew. Under such condition, for the determination of latent heat of fusion of ice, proceed as follows—

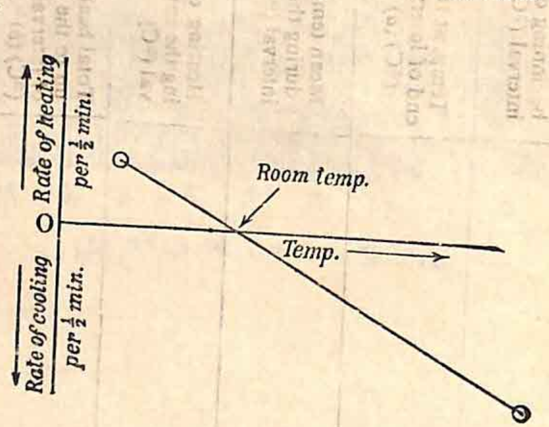
(i) Repeat the operation (1) of method (A).

(ii) Heat the calorimeter containing water for a few minutes so that its temperature rises by 7 to 10°C.

(iii) Place the calorimeter in its box. Suspend the sensitive thermometer (reading up to 1/10 th of a degree) in the calorimeter with the bulb of the thermometer dipping well in the water. Cover it with the lid. By the time this operation is done, the temperature of water must have fallen, and it would be, most likely, just 5 to 6°C above the room temperature. Stirring continuously, note the temperature of water for 2 to 3 minutes at an interval of half minute each—from which rate of cooling can be calculated.

(iv) Repeat the operations (iii) and (iv) of method A. The minimum temperature should be 2 to 3°C below the room temperature. From the observations of temperatures, after the record of minimum temperature, rate of heating can be calculated.

(v) Repeat the operation (v) of method A and find out the mass of ice added.



(Fig. 2.16)

(vi) Enter your results in a table. Adopting the usual method calculate the rate of cooling at a temperature say t_1 (which is above the room temperature) and the rate of heating at another temperature say t_2 (which is below the room temperature). Finally plot these two points indicating rate of cooling at t_1°C and rate of heating at t_2°C. Joining these two points, obtain the required cooling-heating curve. The nature of this curve is shown in the figure 2.16.

(vii) From the cooling-heating curve, obtain the correction for each interval giving due attention to the sign of correction (i.e. cooling should be added to the temperature at the end of the interval while heating up to the end of any particular interval should be subtracted from the temperature at the end of that interval). Obtain the correct temperature that would have reached, if there would have been no transfer of heat either from or to the calorimeter and its contents.

(viii) Repeat the operations (viii) and (ix) of method A. Finally with the knowledge of mean corrected minimum temperature, calculate the value of *L*.

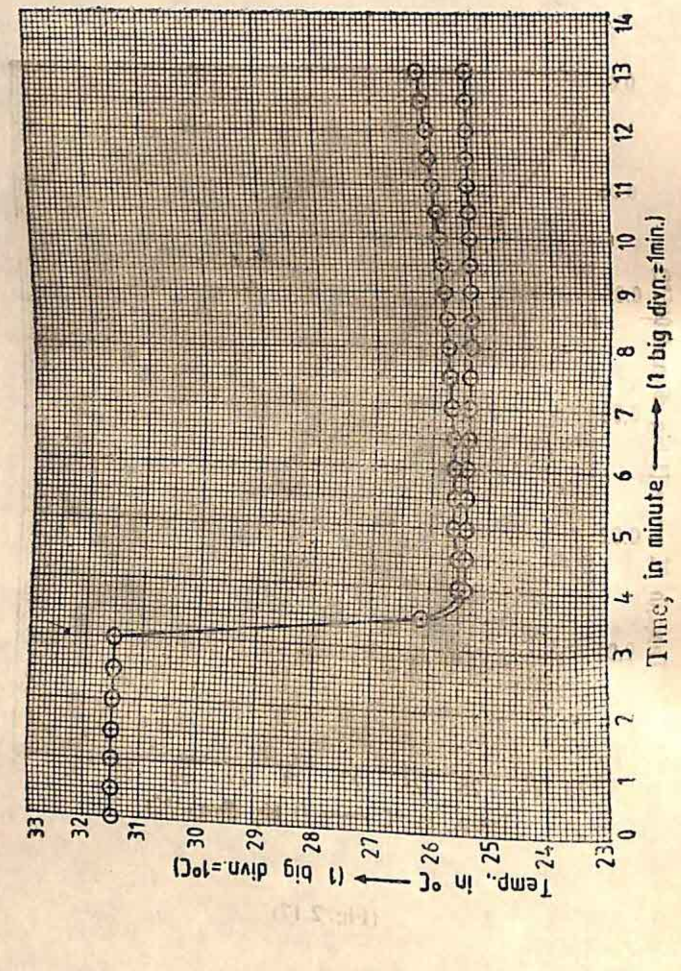
Observations

Draw the table to enter the observations similar to that given in method A.

TABLE I

Time-Temp. Record

1	2	3	4	5	6	7
Time in min.	Temp. of water in calorimeter in °C	Average temp. in °C at the interval of half min.	Cooling during the interval from cooling curve in °C	Total cooling at the end of interval in °C	Corrected Temp. in °C	Average corrected minimum temp. in °C
0	31·55	31·55	0			
½	31·55	31·55	0			
1	31·55	31·55	0			
1½	31·55	31 55	0			
2	31·55	31·55	0			
2½	31·55	31·55	0			
3	31·55	31·55	0			


Temp., in °C ⟶ (1 big divn.=1°C)
33
32
31
30
29
28
27
26
25
24
23
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Time, in minute ⟶ (1 big divn.=1min.)

(Fig. 2.18)

Calculations

Mass of the calorimeter+stirrer $= 80{\cdot}561$ gm. $= m$ gm.

Mass of the calorimeter+stirrer+water contained in it
$= 154{\cdot}662$ gm. $= w$ gm.

$\therefore$ Mass of water taken $= 74{\cdot}101$ gm. $= m_1$ gm.

Initial temperature of water and calorimeter $= 31{\cdot}55°\text{C} = t_1°\text{C}$.

Final (corrected) temperature of mixture after adding the ice
$= 25{\cdot}41°\text{C} = t°\text{C}$.

Temperature of ice $= 0°$C.

Mass of calorimeter+stirrer+water taken+ice added
$= 159{\cdot}460$ gm. $= w_1$ gm.

$\therefore$ Mass of ice taken $= 4{\cdot}798$ gm. $= m_2$ gm.

$\therefore$ Latent heat of fusion of ice

$$L = \frac{(ms+m_1)(t_1-t)}{m_2} - t \text{ cal./gm.}$$

$= 79{\cdot}12$ cal./gm.

Standard value $= 79{\cdot}7$ cal./gm.

$\therefore$ % error $= 0{\cdot}73\%$.

Precautions. (i) Observe all the precautions mentioned in other experiments on calorimetry.

(ii) Before adding to water, dry the ice lump properly with the help of blotting paper.

(iii) Use a single lump of ice as far as possible. Never use a large number of small pieces of ice.

(iv) Use the stirrer of perforated disc type.

(v) Always keep the ice well inside the water and don't allow it to float.

(vi) Use a magnifying glass to read the temperature.

ASSOCIATED EXPERIMENTS

1. Determine accurately the specific heat of liquid. No heating arrangement is supplied.

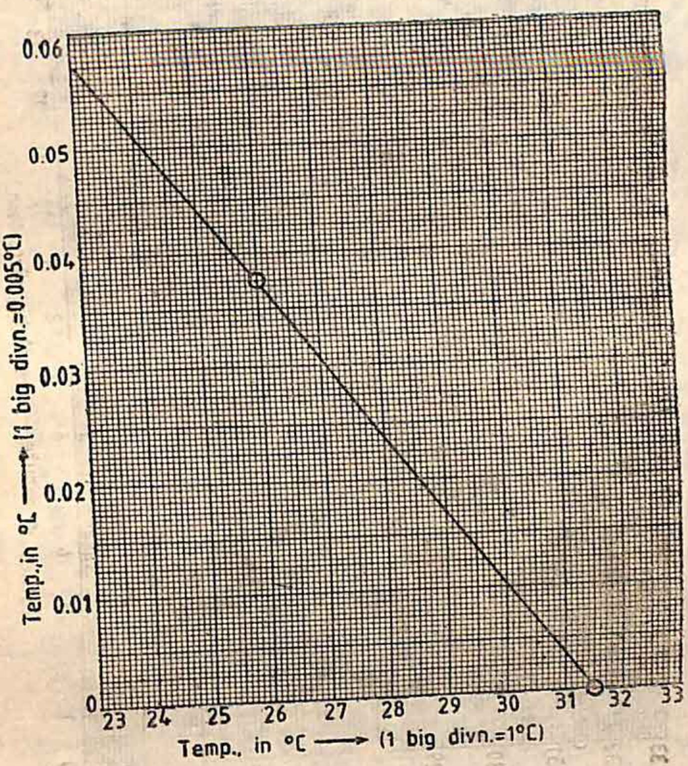
Hint. In place of water, take the given liquid in the calorimeter. Proceed as in the experiment for the determination of latent heat of fusion of ice. Correct the final temperature for radiation loss of heat and taking the latent heat of fusion of ice as 80 cal./gm. calculate the specific heat of the given liquid by the usual method of equating heat loss to heat gain.

If the latent heat of fusion of ice is not supplied, take water in a

1	2	3	4	5	6	7
Time in min.	Temp. of water in calorimete in °C	Average temp. in °C at the interval of half min.	Cooling during the interval from cooling curve in °C	Total cooling at the end of interval in °C	Corrected Temp. in °C	Average corrected minimum temp. in °C
	Ice was dropped					
3½	26·19	28·87	0·0176	0·018	26·172	
4	25·46	25·82	0·0383	0·056	25·404	
4½	25·49	25·48	0·0405	0·096	25·394	
5	25·53	25·51	0·0402	0·137	25·383	
5½	25·56	25·54	0·0400	0·177	25·383	
6	25·60	25·58	0·0397	0·216	25·384	
6½	25·65	25·62	0·0395	0·256	25·394	
7	25·70	25·68	0·0391	0·295	25·405	
7½	25·74	25·72	0·0388	0·334	25·406	
8	25·77	25·76	0·0386	0·373	25·397	
8½	25·81(a)	25·79	0·0384	0·412	25·398(M)	
9	25·86(b)	25·84	0·0380	0·450	25·410	
9½	25·90(c)	25·88	0·0378	0·488	25·412	25·411
10	25·94(d)	25·92	0·0376	0·525	25·415	
10½	25·98(e)	25·96	0·0374	0·562	25·418	
11	26·01(f)	26·00	0·0371	0·600	25·410	
11½	26·05(g)	26·03	0·0368	0·636	25·414	
12	26·08(h)	26·06	0·0365	0·673	25·407	
12½	26·12(i)	26·10	0·0362	0·709	25·411	
13	26·16(j)	26·14	0·0360	0·745	25·415(N)	

TABLE II

Interval of 2½ min.	Rise of temp. in °C	Rise of temp. for 2½ min. in °C	Average rise for 2½ min. in °C	Average rise for ½ min. in °C	Average of ten rises of temp.
From (a)th to (f)th reading	25·81 to 26·01	0·20	0·186	0·0372	$t' = \frac{a+b+\cdots j}{10} = 25{\cdot}99$
From (b)th to (g)th reading	25·86 to 26·05	0·19			
From (c)th to (h)th reading	25·90 to 26·08	0·18			
From (d)th to (i)th reading	25·94 to 26·12	0·18			
From (e)th to (j)th reading	25·98 to 26·16	0·18			


0.06
0.05
0.04
0.03
0.02
0.01
0
Temp.,in °C ⟶ (1 big divn.=0.005°C)
23
24
25
26
27
28
29
30
31
32
33
Temp., in °C ⟶ (1 big divn.=1°C)

(Fig. 2.17)

vessel and surround it completely by ice till water attains the temp. of 0°C.

Now, take the given liquid in the calorimeter and repeat the above experiment adding ice-cooled water in place of ice to the liquid contained in the calorimeter. Correcting the final temperature of the mixture for radiation loss, calculate the specific heat of the given liquid by the usual method of mixture.

2. Determine the quantity of heat absorbed when 15 gm. of hypo is dissolved in 200 c.c. of water.

Hint. Take a calorimeter. Clean, dry and finally weigh it. Next place 200 c.c. of water in the calorimeter and again weigh it—the difference of the two weights will give the mass of 200 c.c. of water. Note the initial temperature by a sensitive thermometer.

Now, put the given amount of hypo in the calorimeter when temperature will begin to fall. Correcting for the radiation, determine the final temperature and hence the fall of temperature θ.

If m be the mass of calorimeter and stirrer made up of the material of sp. heat s and m_1 be the mass of 200 c.c. of water, then amount of heat absorbed.

$$=(ms+m_1)\theta.$$

Since the other quantities are known, calculate the required quantity of heat absorbed.

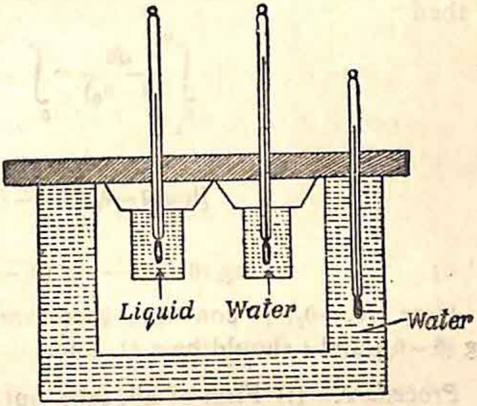
NEWTON'S LAW OF COOLING

EXPERIMENT 9. **To verify Newton's Law of Cooling.**

Apparatus. Two small and exactly indentical calorimeters, a double-walled vessel with lid, two thermometers (one sensitive and one ordinary), stop watch, heating arrangement, measuring cylinder, balance, weight-box.

Description of Apparatus. The double-walled enclosure consists of two rectangular chambers made of brass or copper as shown in figure 2.19. The space between these two chambers is filled with water to maintain the temp. of enclosure constant. The covering lid of the enclosure is made of wood and it has two holes provided with bored rubber stopper through which pass two thermometers for recording the temperature of two liquids. The lower parts of the stems of thermometers are provided with two more stoppers which fit tightly in the calorimeters. These calorimeters remain suspended. The two calorimeters are exactly identical in all respects (mass, shape, size, metal). They are coated with lamp black from outside so that the heat is lost to the surrounding mainly due to radiation when warm liquids are placed in them. The calorimeters are filled with liquid up to a mark engraved in the inner surface so that equal volumes of different liquids can be put in the two calorimeters. In the space between the two chambers, a thermometer is also placed to note the temp. of the surrounding water. With the help of this apparatus Newton's law can be verified or the specific heat of a liquid can be determined by the method of cooling.

Theory. When a body is heated and placed in a surrounding maintained at a lower temp. than the body, it loses heat by way of conduction, convection and radiation. This rate of loss of heat is expressed in terms of Newton's law of cooling which states that *rate of loss of heat from the body is directly proportional to mean difference of temperature between the body and the surrounding provided other conditions remain constant and the difference of temp. is small*. The rate of loss of heat depends on area of the exposed surface of body, nature of surface, and the excess of temp. of body over that of surrounding.



(Fig. 2.19)

If θ is the initial temp. of the body, θ_0 the temp. of the surrounding and δQ be the heat lost in time δt then the rate of loss of heat can be expressed mathematically as

$$-\frac{dQ}{dt}=k(\theta-\theta_0) \qquad \dots (1)$$

where k is a constant depending on the area and the nature of surface.

Let m and s be the mass and the specific heat of the body.

If $\frac{d\theta}{dt}$ be the rate of cooling, then equation (1) can be expressed as

$$-ms\frac{d\theta}{dt}=k(\theta-\theta_0)$$

$$\therefore \quad \frac{d\theta}{dt}=-\frac{k}{ms}(\theta-\theta_0).$$

If a graph is drawn between $\frac{d\theta}{dt}$ along y-axis and excess of temp. along x-axis then it will be a st. line.

If the initial temp. of the body be θ_1 and it falls to θ after a time t_1 then

$$\int_{\theta_1}^{\theta}\frac{d\theta}{(\theta-\theta_0)}=\int_0^t -kdt$$

$$[\log(\theta-\theta_0)]_{\theta_1}^{\theta}=[-kt]_0^t$$

or $$\log(\theta-\theta_0)-\log(\theta_1-\theta_0)=-kt \quad \ldots (2)$$

Here $(\theta_1-\theta_0)$ is constant, therefore the graph drawn between $\log(\theta-\theta_0)$ and t should be a st. line.

Procedure. (i) First of all, take out a calorimeter from the enclosure; clean and dry it. Blacken the outside of the calorimeter with the help of a sooty flame and replace it in the enclosure.

(ii) Take another vessel. Put some liquid in it. Heat it to a temp. of 60°C nearly. Take some heated liquid in a measuring cylinder and fill the calorimeter about three-fourth with the heated liquid taken in the cylinder. Place the cover of enclosure in its position and insert a thermometer in the liquid in the calorimeter through the hole in the covering lid.

(iii) Stir the liquid well and note the reading of thermometer at the interval of every $\frac{1}{2}$ minute or 1 minute till the temp. of hot liquid in calorimeter has fallen sufficiently.

[Occasionally, note the reading of the thermometer inserted in water of the enclosure. If there is any change in it, replace it with fresh water and repeat the expt.]

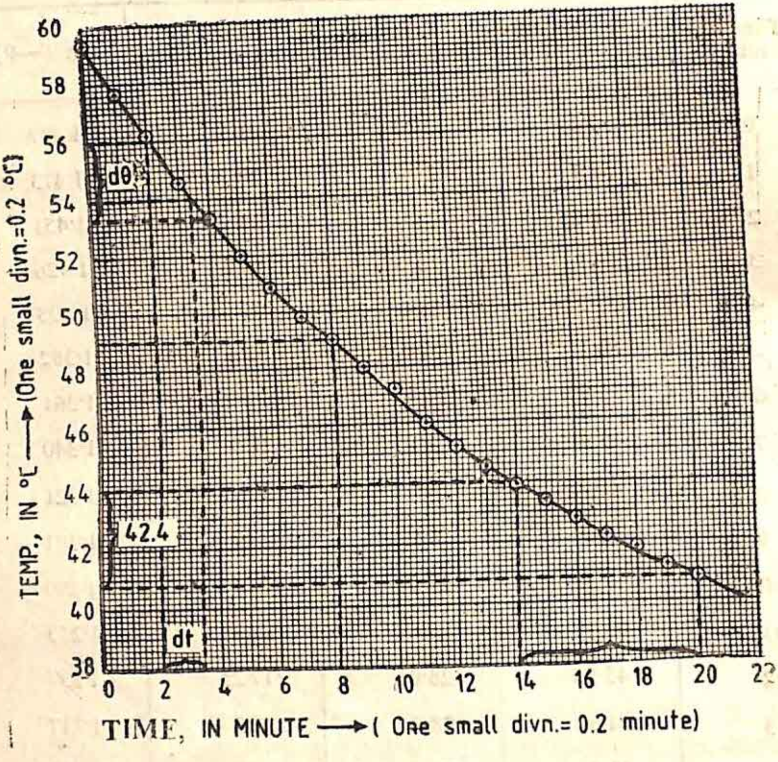
OBSERVATIONS

TABLE I*

Time in min.	Temperature θ°C	Temp. of enclosure θ_0°C	Excess of temp. $(\theta-\theta_0)$	$\log(\theta-\theta_0)$
0	59·4	28·0	31·4	1·497
1	57·7	28·0	29·7	1·473
2	56·25	28·0	28·25	1·451
3	54·7	28·0	26·7	1·426
4	53·3	28·0	25·3	1·403
5	52·1	28·0	24·1	1·382
6	50·95	28·0	22·95	1·361
7	49·9	28·0	21·9	1·340
8	48·95	28·0	20·95	1·321
9	48·0	28·0	20·0	1·301
10	47·15	28·0	19·15	1·290
11	46·0	28·0	18·0	1·255
12	45·25	28·0	17·25	1·237
13	44·5	28·0	16·5	1·217
14	43·9	28·0	15·9	1·201
15	43·35	28·0	15·35	1·186
16	42·8	28·0	14·8	1·170
17	42·2	28·0	14·2	1·152
18	41·8	28·0	13·8	1·140
19	41·2	28·0	13·2	1·121
20	40·75	28 0	12·75	1·105

Calculations and Graphs. (i) Plot graph with time along x-axis and temp. along y-axis. It would be a curve as shown in fig. 2.20. Choose a number of points on the curve and determine the slope of the curve at these points. The slopes give the values of $\frac{d\theta}{dt}$ at these temperatures.

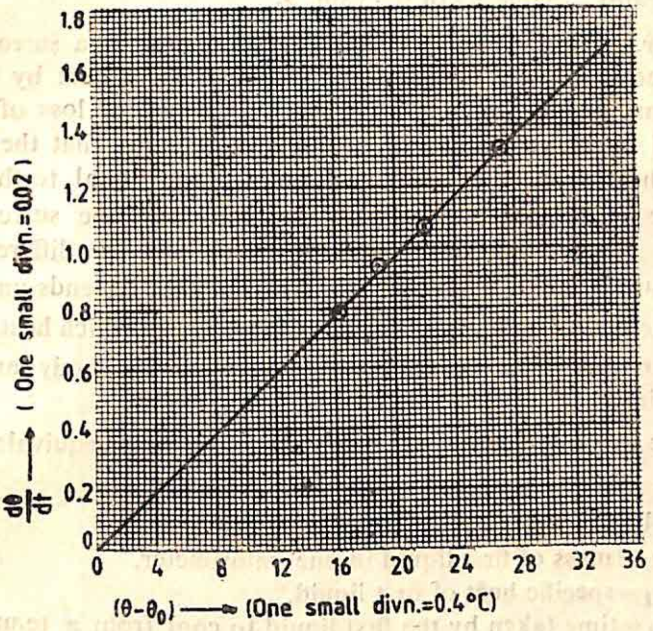
**Table based on readings from graph 2.20.*



(Fig. 2.20)

Temp. of enclosure θ_0°C	Value of temp. (θ°C) from graph	Excess of temp. $\theta-\theta_0$	From graph $d\theta$	From graph dt	$\frac{d\theta}{dt}$
28·0	55·0	27·0	2	1·5	1·33
28·0	51·15	23·15	4·3	4	1·07
28·0	47·1	19·1	3·8	4	0·95
28·0	44·4	16·4	3·15	4	0·79

(ii) Draw another graph with excess of temperature $(\theta - \theta_0)$ along



(Fig. 2.21)

x-axis and $\frac{d\theta}{dt}$ along y-axis. It will be a straight line, proving the validity of Newton's law of cooling, as shown in fig. 2.21.

(iii) Draw another graph with time along x-axis and log $(\theta - \theta_0)$ along y-axis. This would be a straight line as shown in fig. 2.22.

Conclusion. The nature of the graph supports Newton's law of cooling.

Precautions. (i) Do not raise the temperature of the liquid to its boiling point.

(ii) The calorimeters should be properly suspended in the enclosure in order that it does not touch the sides of the enclosure.

(iii) Note the thermometer carefully.

EXPERIMENT 10. Determination of the specific heat of a liquid by method of cooling.

Apparatus. Same as in the expt. 9.

Theory. When a body is heated and placed in a surrounding maintained at a lower temperature to cool, it loses heat by way of conduction, convection, and radiation. This rate of loss of heat is expressed by Newton's law of cooling which states that the rate of loss of heat from the body is directly proportional to the mean difference of temperature between the body and the surrounding provided other conditions remain constant and the difference of temperature is small. Thus the rate of loss of heat depends on

(a) the nature and area of surface exposed from which heat is lost,

(b) the difference of temperature between the body and the surrounding.

As the two calorimeters are indentical, their water equivalents are the same.

Let w be the water equivalent of each calorimeter,

m_1 = mass of first liquid in one calorimeter,

s_1 = specific heat of first liquid,

t_1 = time taken by the first liquid to cool from a temp. θ_1°C to θ_2°C,

m_3 = mass of second liquid in the other calorimeter,

s_2 = specific heat of second liquid,

t_2 = time taken by the second liquid to cool from the same range of temperature θ_1°C to θ_2°C.

∴ Heat last by first liquid in time t_1

$$=(m_1s_1+w)(\theta_1-\theta_2) \text{ cal.}$$

∴ Heat lost by the first liquid in per unit time

$$=\frac{(m_1s_1+w)(\theta_1-\theta_2)}{t_1} \quad .. \quad (1)$$

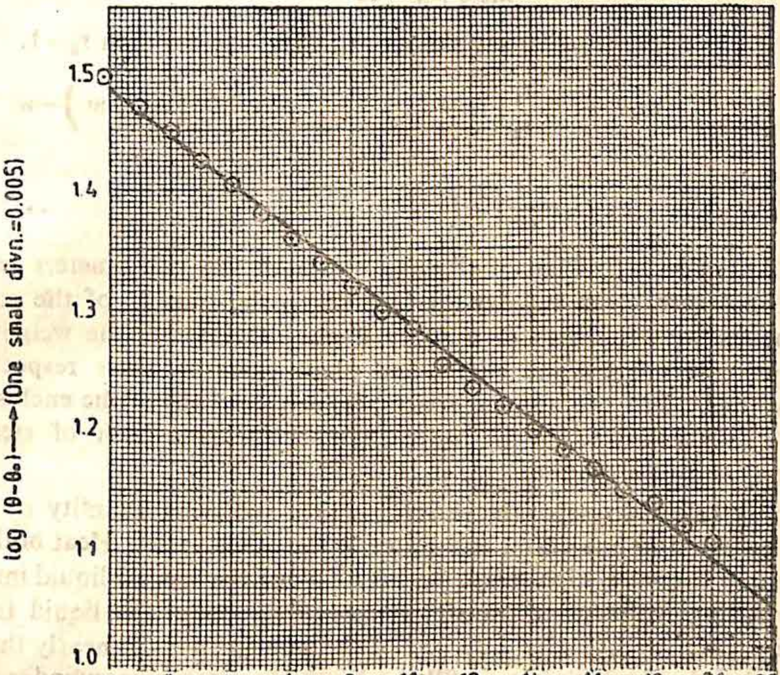
Heat lost by second liquid in time t_2

$$=(m_2s_2+w)(\theta_1-\theta_2)$$

∴ Heat lost by second liquid in per unit time

$$=\frac{(m_2s_2+w)(\theta_1-\theta_2)}{t_2}. \quad .. \quad (2)$$

The rate of loss of heat under the similar condition of temperature difference, area and nature of surface exposed, must be the same


1.5
1.4
1.3
1.2
1.1
1.0
log (θ−θ₀) ——→(One small divn.=0.005)
0
2
4
6
8
10
12
14
16
18
20
22
Time .In minute ——→(One small divn.=0.2 minute)

(Fig. 2.22)

and so

$$\frac{(m_1s_1+w)(\theta_1-\theta_2)}{t_1}=\frac{(m_2s_2+w)(\theta_1-\theta_2)}{t_2}$$

$$\therefore \qquad \frac{m_1s_1+w}{t_1}=\frac{m_2s_2+w}{t_2}$$

$$\text{or} \qquad \frac{m_1s_1+w}{m_2s_2+w}=\frac{t_1}{t_2} \qquad \text{..} \quad (3)$$

If one of the liquids, say the second one, is water then $s_2=1$.

$$\therefore \qquad m_1s_1+w=\frac{t_1}{t_2}\left(m_2+w\right) \quad \therefore \quad m_1s_1=\frac{t_1}{t_2}\left(m_2+w\right)-w$$

$$\therefore \qquad s_1=\frac{1}{m_1}\left[\frac{t_1}{t_2}\left(m_2+w\right)-w\right] \qquad \text{..} \quad (4)$$

Procedure. (i) First of all, take out both the calorimeters from the enclosure, clean and dry them. Blacken the outside of the calorimeters with the help of a sooty flame. Determine the weight of empty calorimeters and stirrer and place them in their respective positions. Fill the annular space between the walls of the enclosure with cold water so that the inner chamber forms a bath of steady temp. Insert a thermometer in it.

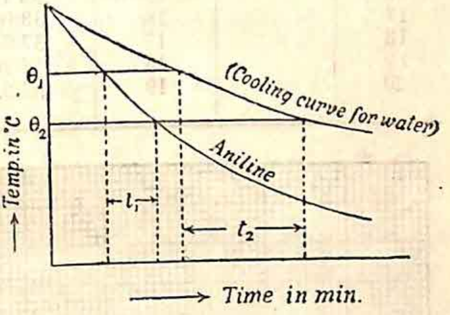
(ii) Take two separate vessels. Place sufficient quantity of the given liquid in one vessel and water in the other vessel. Heat both of them to the same high temp. say 60°C. Pour the heated liquid into a measuring cylinder and transfer measured volume of the liquid from the measuring cylinder into one of the calorimeters till nearly three-fourth vol. of calorimeter is filled. Wash the measuring cylinder and put heated water in it. With the help of this measuring cylinder transfer equal volume of water (as that of liquid) to the other calorimeter. Replace the lid over the double-walled enclosure and insert the thermometers in the calorimeters.

(iii) Stir both the liquids gently and read the temperatures at the interval of every 1 minute with the help of a stop watch till the temperatures fall below 40°C. Readings should be noted when the two thermometers indicate approximately the same temp. The following method should be adopted for convenience in taking the readings. Note the reading of the thermometer immersed in liquid when the seconds hand of the stop watch is at 60 and note the reading of the thermometer immersed in water on the other calorimeter when the seconds hand is at 30. In this way continue to take reading till the temp. falls below 40°C.

(iv) Take out the calorimeters with their contents from the enclosure and allow them to cool to almost the room temp. Remove the thermometers and weigh them with their contents separately and hence determine the mass m_1 and m_2 of liquid and water respectively.

Note down the specific heat of the material of the two calorimeters from the table of constants and hence find out the water equivalent of the calorimeter.

Draw two cooling curves on the same graph paper as shown in fig. 2.23 for the liquid and water both. Determine from them the times t_1 and t_2 taken by the liquid and water respectively in falling from the same temperature θ_1°C to θ_2°C.



(Fig. 2.23)

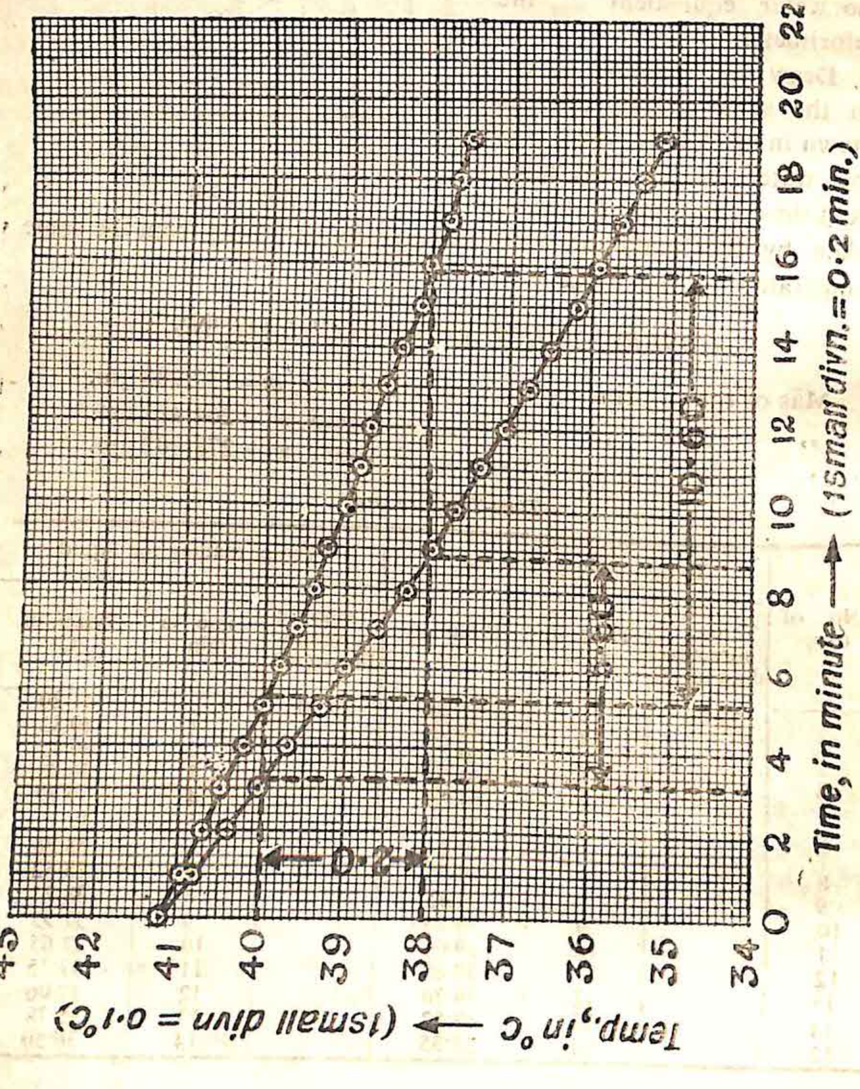
OBSERVATIONS AND CALCULATIONS

Mas of the calorimeter with lid and stirrer, $m = 157·983$ gm.
" " " " " + liquid, $w_1 = 264·823$ gm.
" " " " " + water, $w_2 = 278·403$ gm.

Time-Temp. record

No. of obs.	Temp. reading for water			Temp. reading for liquid		
	Temp. of surrounding in °C	Time in min.	Temp. in °C.	Temp. of surrounding in °C	Time in min.	Temp. in °C
1	29·80	0	41·20	29·80	0	41·20
2		1	40·95		1	40·82
3		2	40·72		2	40·45
4		3	40·50		3	40·08
5		4	40·26		4	39·72
6		5	40·04		5	39·35
7		6	39·84		6	38·98
8		7	39·65		7	38·62
9		8	39·45		8	38·27
10		9	39·25		9	37·95
11		10	39·06		10	37·65
12		11	38·88		11	37·35
13		12	38·70		12	37·06
14		13	38·52		13	36·78
15		14	38·35		14	36·50

No. of *Obs.*	Temp. reading for water			Temp. reading for liquid		
	Temp. of surrounding in °C	Time in min.	Temp. in °C	Temp. of surrounding in °C	Time in min.	Temp. in °C
16		15	38·18		15	36·20
17		16	38·00		16	35·92
18		17	37·84		17	35·65
19		18	37·70		18	35·39
20		19	37:55		19	35·15



(Fig. 2.24)

From the graph—

The time (t_1) required by the liquid in falling from 40°C (θ_1) to 38°C(θ_2) = 5·60 min.

The time (t_2) required by water to fall through the same range = 10·60 min.

Mass (m_1) of the liquid taken = $(w_1 - m)$ = 106·84 gm.

,, (m_2) of the water taken = $(w_2 - m)$ = 120·40 gm.

s the sp. heat of the material of the calorimeter = 0·094

∴ Its water equivalent $w = ms$ = 14·84 gm.

s_1 = 0·53 cal. per gm. per °C.

Result. $s_1 = 0{\cdot}53$.

Precautions. (i) On the graph choose a large range of temperature for calculating the time of fall.

(ii) The nature of the external surface of the calorimeter and the temp. of the enclosure should remain the same in the two cases.

(iii) In case of inflammable liquids like kerosine oil, do not raise the temp. too high otherwise it may catch fire.

(iv) Do not raise the temp. of liquids to the boiling points.

(v) The two calorimeters should be properly suspended in the enclosure in order that they do not touch the sides of enclosure.

ASSOCIATED EXPERIMENTS

1. Compare the specific heat of the liquids supplied.

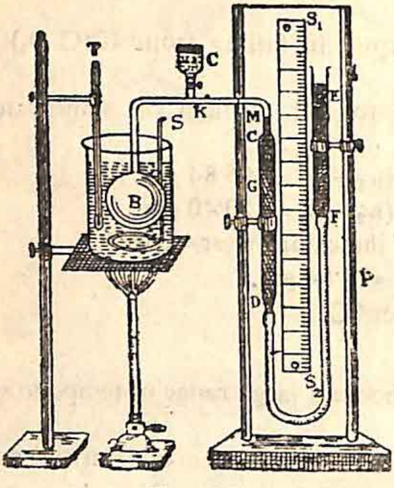
Hint. Repeat the experiment for the determination of specific heat of liquid by the method of cooling. First perform the experiment with one liquid and then repeat it with the second liquid taking in the same calorimeter. In each case, determine the times of cooling of liquid for the same interval of temperature. Finally, employing the relation (3) in the theory of the above experiment find the ratio of specific heats s_1 and s_2 of the two liquids.

CONSTANT VOLUME AIR THERMOMETER

Expt. 11. Measurement of the coefficient of increase of Pressure of air at constant volume.

Apparatus. Constant volume air thermometer, mercury thermometer, water bath and an arrangement for boiling water.

Description of the apparatus. It consists of a glass bulb B whose temperature can be varied by means of immersing it in a water bath



(Fig. 2.25)

provided with a thermometer *T* and a stirrer *S*. The bulb contains some well dried air and is connected by means of a capillary tube bent twice at right angles to a wider glass tube *G*, having a mark at *M*. The lower end of *G* is joined to another glass tube *EF* of relatively wide bore, with a thick-walled Indian rubber tube. Glass tube *EF* serves as a mercury reservoir and can be raised or lowered at will along a vertical stand and may be clamped at any position. The whole thing is mounted properly on a vertical wooden stand provided with levelling screws at the base and a vertical wooden scale S_1S_2 is attached to it between *G* and *EF* so that the difference of mercury level in *G* and *EF* can be measured. The part of the tube *EF*, the whole of the rubber tube and the tube *DG* up to *M* contain pure and dry mercury. The reservoir is raised or lowered so that the level of mercury in *G* is made to coincide always with mark *M* made on it to ensure constancy of the volume of air enclosed in the bulb *B* and the tube *K*. The pressure of air enclosed in the bulb *B* and tube *K* is determined by noting the difference in the levels of mercury in the two limbs and addding this to or subtracting it from the atmospheric pressure as the case may be. For accurate measurement of the difference of levels of the mercury surfaces, the apparatus should be so arranged that the two limbs may be close together beside a paper scale attached to the frame. Dry air free from CO_2 is introduced by passing it through a side tube *K* containing $CaCl_2$ and soda-lime.

Theory. If the volume of the given mass of gas is kept constant and the temperatures of the same mass of the gas is allowed to increase, then it is found that the pressure also increases for each degree centigrade increase of temperature. The pressure increases by a constant fraction of the pressure at 0°C. This fraction is called the pressure coefficient γ_v of the gas at constant volume.

If p_0 be the pressure of the gas at 0°C and p be the pressure at t°C (both at a constant volume), then

$$p = p_0(1+\gamma_v t)$$

$$\therefore \ \gamma_v = \frac{p - p_0}{p_0 . t}.$$

Similarly if p_1 be the pressure of the enclosed air at t_1°C and p_2 be the pressure of the same mass of gas at t_2°C when the volume is kept constant, then

$$p_1 = p_0(1+\gamma_v . t_1)$$

$$\text{and} \qquad p_2 = p_0(1+\gamma_v . t_2)$$

$$\therefore \ \frac{p_1}{p_2} = \frac{1+\gamma_v . t_1}{1+\gamma_v . t_2}$$

$$\gamma_v = \frac{p_2 - p_1}{p_1 t_2 - d_2 t_1}.$$

Procedure. (i) Make the apparatus vertical with the help of a plumb line and levelling screws attached to its base. If the levelling screws are not provided in the instrument, then use a few small wooden wedges. Now take a beaker sufficiently large to accommodate the glass bulb *B* and fill it with water so that the bulb *B* and as much of the tube *K* as possible is completely submerged at room temperature. Immerse a mercury thermometer graduated up to 100°C in the bath close to *B*. Let a piece of cork fixed to the end of the stirrer *S* in the bath serve the purpose of handle of the stirrer.

(ii) See that the stop-cock *C* attached to *K* is tightly fitting. If it is not so, then lower the reservoir *EF* so that the mercury level in tube *G* is a little below the mark *M*. Now take out the cock and put a little vaseline over it and restore back to the same position to ensure that the tube is air-tight.

(iii) Adjust the position of the reservoir *EF* so that the mercury level just touches the mark *M* in the glass tube *G*. Read the levels of mercury in *G* and *EF*. The use of set squares may be helpful in taking these readings as one edge of it is placed parallel to the scale and the other edge (at right angles) is set tangential to the mercury meniscus. After stirring the water, the temperature of the bath is noted by the thermometer. Note down the height of barometer.

(iv) Heat the water in beaker slowly, until the temperature rises by about 8°C by a bunsen flame. Maintain the temperature of the bath constant properly for about five minutes near about that value by manipulating the flame of the burner. Due to rise of temperature of the gas in the bulb *B*, the gas expands and the mercury level in *G* will be depressed below *M*. Stir well and raise the arm *EF* to bring the mercury level in *G* again at the constant mark *M*. See that the mercury level in *G* just touches the mark *M*. Note down the readings of the scale corresponding to the free surface of mercury in *EF* and *G* and read the thermometer.

(v) Raise further the temperature of the bath slowly by steps of 8° and repeat the process (iv). Continue taking readings till the temperature is about 100°C. Note the height of the barometer and the temperature of the bath. But before taking final readings keep the temperature of the bath steady for about 4 to 5 minutes in each case because the air inside the glass takes time to attain the temperature of bath due to the fact that glass is a bad conductor of heat.

(vi) Next remove the burner and allow the water in beaker to cool, taking care that the mercury in *G* does not go over into the bulb *B* and for this, lower the reservoir *EF* so that the level in *G* is much below the mark *M*. Stir the water continuously as the temperature falls. Again take readings of mercury levels for the same temperatures for which redings of pressure had been taken when the temperature of the bath was rising, keeping the volume constant. This should be continued till the room temperature is attained. Note the height of barometer again and determine the mean barometric height. Let it be *H* cm. of *Hg*.

(vii) If time is available, then two or three readings should be noted for temperatures below the room temperature by adding ice to water.

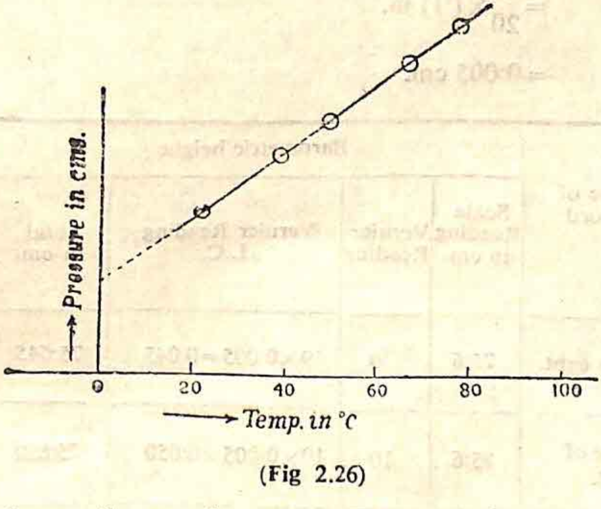
(viii) Calculate the difference of scale readings (h) corresponding to the constant mercury level at *M* in tube *G* and the mercury level in the reservoir *EF* at each temperature. Thus the pressure of gas in bulb *B* at any temperature is equal to the barometric height plus or minus the difference of mercury levels in *G* and *EF* at that temperature. Mathematically it can be shown as $H \pm h$. Pressure of the gas would be $(H+h)$ or $H-h)$ according as the mercury level in the reservoir *EF* is above or below the constant mercury level at *M*.

(ix) Record the results as shown below in the table. Note the readings for the mark M at the top of the table. Then, calculate γ_v from the mean pressures obtained at different temperatures taking the 1st and the 6th, the 2nd and the 7th and so on and finally obtain the mean value of γ_v.

(x) Then plot the graph between the temperature of the gas as abscissa having zero as origin and the pressure exerted by it in cm. of mercury as ordinate. The graph would be a straight line. On the graph, note two pressures p_1 and p_2 corresponding to two chosen temperatures t_1 and t_2 and calculate γ_v from these data.

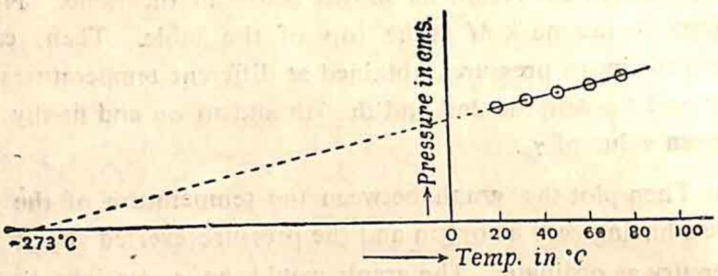
The pressure of the enclosed gas at 0°C can also be obtained from this graph by extrapolation. For this produce the straight line to cut the y-axis for $t=0$. The point of intersection of this st. line with y-axis for $t=0$ gives the value of p_0. The value of γ_v can also be calculated from the formula

$$\gamma_v = \frac{p_t - p_0}{p_0 . t}$$



(Fig 2.26)

Now plot another graph on a smaller scale of temperature along x-axis and mean of pressure along y-axis. Then produce the st. line



(Fig. 2.27)

so obtained towards the side of lower temperature. The intersection of this st. line with the x-axis (temp. axis) gives the absolute zero.

OBSERVATION

(A) Barometer Reading

Smallest division of main scale $= 0{\cdot}1$ cm.

$$20 \text{ v.d.} = 19 \text{ s.d.}$$

$$\therefore \quad \text{L.C.} = (1 - \tfrac{19}{20}) \text{ s.d.} = \frac{1}{20} \text{ s.d.}$$

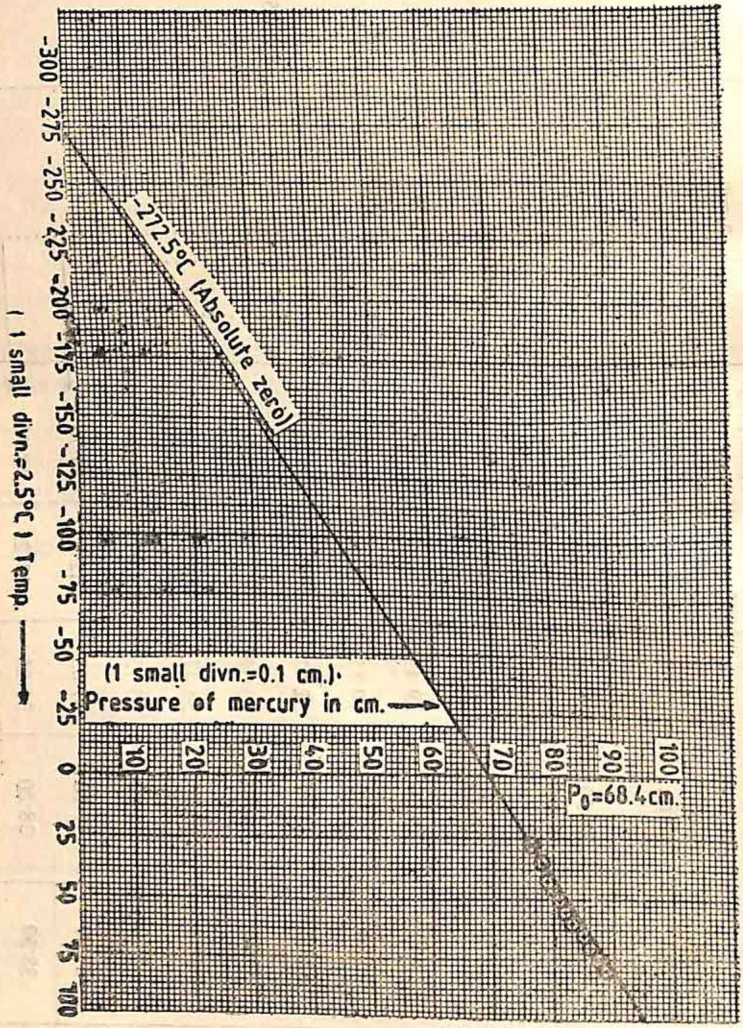
$$= \frac{1}{20} \times (\cdot 1) \text{ m.}$$

$$= 0{\cdot}005 \text{ cm.}$$

No. of obs.	Time of record	Barometric height				Mean height (H) in cm.
		Scale Reading in cm.	Vernier Reading	Vernier Reading × L.C.	Total in cm.	
1	Before expt.	75·6	9	$9 \times 0{\cdot}005 = 0{\cdot}045$	75·645	75·65
2	Middle of expt.	75·6	10	$10 \times 0{\cdot}005 = 0{\cdot}050$	75·650	
3	After expt.	75·6	11	$11 \times 0{\cdot}005 = 0{\cdot}055$	75·655	

(B) Pressure-Temp. Record. Constant (fixed) Level of mercury (M) = 25·00 cm.

No. of observation	Mean barometric height in cm	Temp. of bath in (°C)	Reading of Hg level in EF arm in cm			Pressure difference in cm	Total Pressure of closed air in cm	$\gamma_v = \frac{p_2 - p_1}{p_1 t_2 - p_2 t_1}$	Mean γ_v
			Temp. rising	Temp. falling	Mean				
1	75·65	28 6	25·30	25·50	25·40	0·40	76·05		
2		35·0	27·10	27·00	27·05	2·05	77·70 ←	→0·00359	
3		40·0	28·30	28·40	28·35	3·35	79·00 ←	→0·00358	
4		45·0	29·40	29 50	29·45	4·45	80·10 ←	→0·00369	
5		50·0	30·80	30·90	30·85	5·85	81·50 ←	→0·00358	
6		55·0	32·00	32·05	32·02	7·02	82·67 ←		0·00362
7		60·0	33·30	33·30	33·30	8·30	83·95 ←	→0·00363	
8		65·0	34·50	34·45	34·47	9·47	85·12 ←		
9		70·0	35·70	35·80	35·75	10·75	86·40 ←		
10		75·0	37·00	37·10	37·05	12·05	87·70 ←		
11		80·0	38·30	38·20	38·25	13·25	88·90 ←		



(Fig. 2.28)

Calculation :

Mean $\gamma_v = 0{\cdot}00362$ per °C.

Standard value of $\gamma_v = 0{\cdot}00366$ per °C.

$\therefore$ % error $= 1{\cdot}09\%$.

From Graph,

Absolute zero $= -272{\cdot}5$ °C.

$\therefore \quad \gamma_v = \frac{1}{272 \cdot 5} = 0 \cdot 00367$ per °C.

$\therefore \quad \%$ error $= +0 \cdot 27\%$.

Precautions : (i) The bores of the tube G and EF should be the same to avoid the error due to capillarity.

(ii) The temperature of the bath should be kept constant for at least 5 minutes at each observation by proper manipulation of burner.

(iii) The bath must be well stirred.

(iv) The air to be introduced should be made dry before introduction. As the vapours do not obey the gas laws properly, presence of even a small quantity of moisture will affect the result.

(v) At the end of expt., the open limb of the apparatus should be lowered enough to avoid the suction of mercury in the bulb B.

(vi) The apparatus and the scale should be vertical.

(vii) In taking the readings of mercury levels, the error due to parallax should be avoided as far as practicable.

(viii) Mercury used in the manometer limbs should be pure, because if it is impure, it may stick to the walls of the tube. Hence before taking final observation, the limbs should be tapped.

(ix) As the expansion of the bulb has not been considered during the experiment hence γ_v so obtained should be corrected.

(x) As it becomes difficult to maintain the temperature constant above 60°C usually, hence the rise of temperature is preferred by 5°C at a time instead of 8°C.

ASSOCIATED EXPERIMENTS

1. Determine the melting point of the given substance using a constant volume air thermometer.

Hint. Draw a capillary tube and break it somewhere in the middle. Heat the given substance in a crucible. When it melts, introduce the molten mass in the capillary tube. Seal one end of the capillary. Hold the capillary tube in hot gases just above Bunsen flame and slightly tapping the tube, remove the air bubble, if any, present in the molten mass. Break about 10 cm of the capillary tube.

Now set up the constant volume air thermometer surrounding its bulb completely with ice all the time. Adjust the height of the reservoir till the level of mercury in the left limb of the apparatus touches the mark M. Read the difference of levels of mercury in the two limbs. Wait for five minutes and in the mean time take two or three more readings to check the accuracy. Take also the reading of the barometer.

Next, tie the capillary tube to the bulb of the apparatus and place the two in the water bath. Heat the bath when temperature of the bath will increase and after some time, the given substance in the capillary tube will begin to melt. Keeping the mercury level in the left limb touching the mark M, read the difference in the levels of mercury in the two limbs when the substance melts. Take also the barometer reading.

Now, raise the temperature further and finally maintain the bath at the boiling point of water. Adjust the height of the reservoir and keeping the level of mercury touching the mark M, read the difference of levels of mercury in the two limbs. Also take the barometer reading.

Stirring continuously allow the bath to cool. When the substance just solidifies, read the difference of levels of mercury in the two limbs in the usual way, and also take the barometer reading. If time permits repeat the above operation thrice.

Calculate the pressures of enclosed air (which will be equal to the barometer reading ± the difference of levels in the two limbs, depending upon whether the level of mercury in the left limb is lower or higher than that in the right limb) at temperatures of melting ice, boiling water and melting and solidifying substance. The barometer readings would be practically constant during the whole experiment. If not, associate the difference of the levels with the corresponding barometer reading. Also, from the observed barometer reading at boiling point of water, calculate its temperature from the following data.

At pressure 760 mm., the boiling point of water is 100°C and per 26 mm. decrease of pressure, there is a decrease of 1°C temp. in the boiling point.

Now, plot the temperatures 0°C, and the boiling point of water and the corresponding pressures. Join the two points by a straight line. From the graph, find the temperature corresponding to the mean pressures for the melting substance. This will give the melting point of the substance given.

2. Using a constant volume air thermometer test the correctness of the following graduations of the given mercury-in-glass thermometer: 45°C, 50°C and 55°C.

Hints. Repeat the above experiment and taking two readings of pressures corresponding to the melting ice and boiling water, draw a straight line graph.

Now, put the bulb of the apparatus in a water bath and also suspend a mercury-in-glass thermometer in it. Stirring all the time, heat the water bath. Adjusting the height of the reservoir in the usual manner, read the difference of pressures in the two limbs when the thermometer reads 45°, 50° and 55°C respectively. Noting the barometer reading, calculate the total pressures p_1, p_2 and p_3 corresponding to these temperatures.

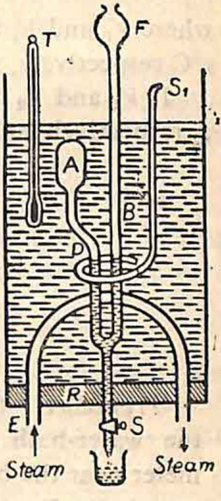
From the graph, find the temperatures corresponding to these pressures. These temperatures will give the actual values of temperatures 45°, 50° and 55°C.

CONSTANT PRESSURE AIR THERMOMETER

EXPERIMENT 12. Determination of the coefficient of gas at constant pressure.

Apparatus. Constant pressure air thermometer, ordinary mercury thermometer, boiler, beaker.

Description of apparatus. CONSTANT PRESSURE AIR THERMOMETER : It consists of a U-tube *DB* the end *B* of which is open to atmosphere, and is terminated in a funnel *F.* The other end is terminated by a bulb *A* (25 cc.). A part of the stem of *D* adjacent to *A* is graduated in cc.



(Fig. 2.29)

The U-tube has a short tube attached to its bend which serves as an outlet. This outlet tube is provided with a stop-cock *S* by which any excess liquid (acid) in the U-tube can be drained out and can be operated from outside. The U-tube is placed in a water-bath contained in an outer jacket *F* and the quantity of water is so taken that the air-bulb *A* is completely immersed in it but the open limb *B* projects out. This outer jacket *F* is made of thick glass cylinder whose bottom is closed with the help of a stout rubber cork *R*. A bent copper tube *E* is in the form of inverted U and enters through this cork into the water-jacket and leaves it again through the same rubber cork so that its free ends are outside. The stream is passed through this copper tube and by regulating the supply of steam, the temperature of water bath can be maintained at any desired value. A thermometer T is suspended in water-bath near the bulb A and records the temperature of the bath. The bath is stirred constantly by a stirrer S_1, to keep the temperature uniform, by means of a string attached to its upper end going round a pulley at the top. Conc. H_2SO_4 is poured in the U-tube from its outer mouth F and the levels of the acids in the two arms are always kept in the same horizontal plane either by adding acid or by draining off the acid in a beaker by opening the stop-cock S. The air in A is then at the atmospheric pressure and its temperature raised and the volume is read from the graduation. The whole apparatus is mounted on a wooden frame.

Theory. If the pressure of the given mass of gas is kept constant, the increase in volume of the gas for one degree rise of temperature has a constant ratio to its original volume at 0°C. Hence, the co-efficient of expansion γ_p of the gas is given by

$$\gamma_p = \frac{V_t - V_0}{V_0 . t} \quad .. \quad (1)$$

where V_0 and V_t are the volumes of a given mass of the gas at 0°C and t°C respectively, pressure remaining constant.

If V_1 and V_2 be the volumes of the gas at temperatures t_1 and t_2 respectively at a constant pressure then,

$$V_1 = V_0(1+\gamma_p . t_1)$$

and

$$V_2 = V_0(1+\gamma_p . t_2)$$

$$\frac{V_2}{V_1} = \frac{1+\gamma_p . t_2}{1+\gamma_p . t_1}$$

$$\gamma_p = \frac{V_2 - V_1}{V_1 t_2 - V_2 t_1} \quad .. \quad (2)$$

Procedure. (i) See that the bulb A is completely immersed in the water-bath and stop-cock is air-tight. Then suspend a thermometer near the bulb A in water bath and remove the cork closing the mouth F. Pour conc. H_2SO_4 in the open arm B until the acid stands at higher level than in the closed arm D. Now open the stop-cock slightly and allow the acid of the tube drop by drop in the beaker till the level of acid in both the arms is the same. Stir the bath well and then read its temperature and also read the volume of the enclosed air (gas) at room temperature. Note the height of barometer.

(ii) Allow the steam to pass through the copper tube *E*. The temperature of the bath would rise. The temperature rise causes the air in the bulb to expand and force down the acid which rises in the open limb. The increase of the temperature should be slow and it can be regulated by controlling the supply of steam. When the temperature has increased by about 8°C, cut off the steam, stir the bath well and adjust the levels of acids to be the same in both the limbs either by running out the acid by opening the stop-cock or by adding more acid to *B* as the case may be. Thus after making the acid levels the same in both the limbs, read the volume of gas and the temperature of the bath.

(iii) Pass the steam again and raise the temperature of water bath by steps of 8°C and continue taking readings as in (ii) till the temperature is about 100°C. Note the height of the barometer again.

(iv) The bulb is allowed to cool slowly. Care should be taken to see that the fall of temperature should be as slow as the rise of temperatures in the operations (ii) and (iii). When the temperature has fallen much below 100°C, it would be seen that the fall of temperature would be very slow and thus more time will be consumed. Hence, let the tap-water pass through the outer tube *E*. Go on taking readings of the volume of the gas for the same temperature for which readings of volumes had been taken when the temperature was rising, bringing always the acid-levels in the two arms in the same horizontal plane as described in operations (ii) and (iii).

(v) In case, time is available, add some pieces of ice to the water bath and take two or three readings below the room temperature as in operations (ii) and (iii).

(vi) Tabulate the results as in the table shown below and hence calculate γ_p the coefficient of expansion of volume from observations 1st and 6th and 2nd and 7th and so on. Take the mean of the results.

(vii) Plot a graph with temperature along the *x*-axis having 0°C as origin and mean volume along *y*-axis. The graph will be a straight line. From the graph get V_0 by extrapolation. Also from the graph take a value of the volume V_t corresponding to a high value of t (75°C) and substitute these quantities in equation (1) to get the value of γ_p.

(viii) Draw another graph of temperature and volume as abscissa and ordinate respectively and extrapolate the st. line so obtained towards the lower side of the temperature. This should intersect the x-axis at $-273°$C which would prove that volume of the gas becomes zero at $-273°$C. It will be found that the value of γ_p is $\frac{1}{273}$.

Observations and Calculations

No. of observations	Barometer reading	Temp. °C	Volume of enclosed gas in c.c.			$\gamma_p = \frac{V_2 - V_1}{V_1 t_2 - V_2 t_1}$
			Temp. rising	Temp. falling	Mean	
1	75·55	32·5	26·4	26·4	26·4	→0·004068
2	cm	40·5	27·15	27·15	27·15	→0·003936
3	(of mercury)	48·5	28·0	28·0	28·0	→0·003683
4		56·5	28·7	28·8	28·75	
5		64·5	29·4	29·4	29·4	
6		72·5	30·1	30·1	30·1	→0·003745
7		80·5	30·8	30·8	30·8	
8		88·5	31·6	31 6	31·6	

$$\text{Mean } \gamma_p = 0{\cdot}003858.$$

From graph $V_0 = 23{\cdot}6$ c.c.

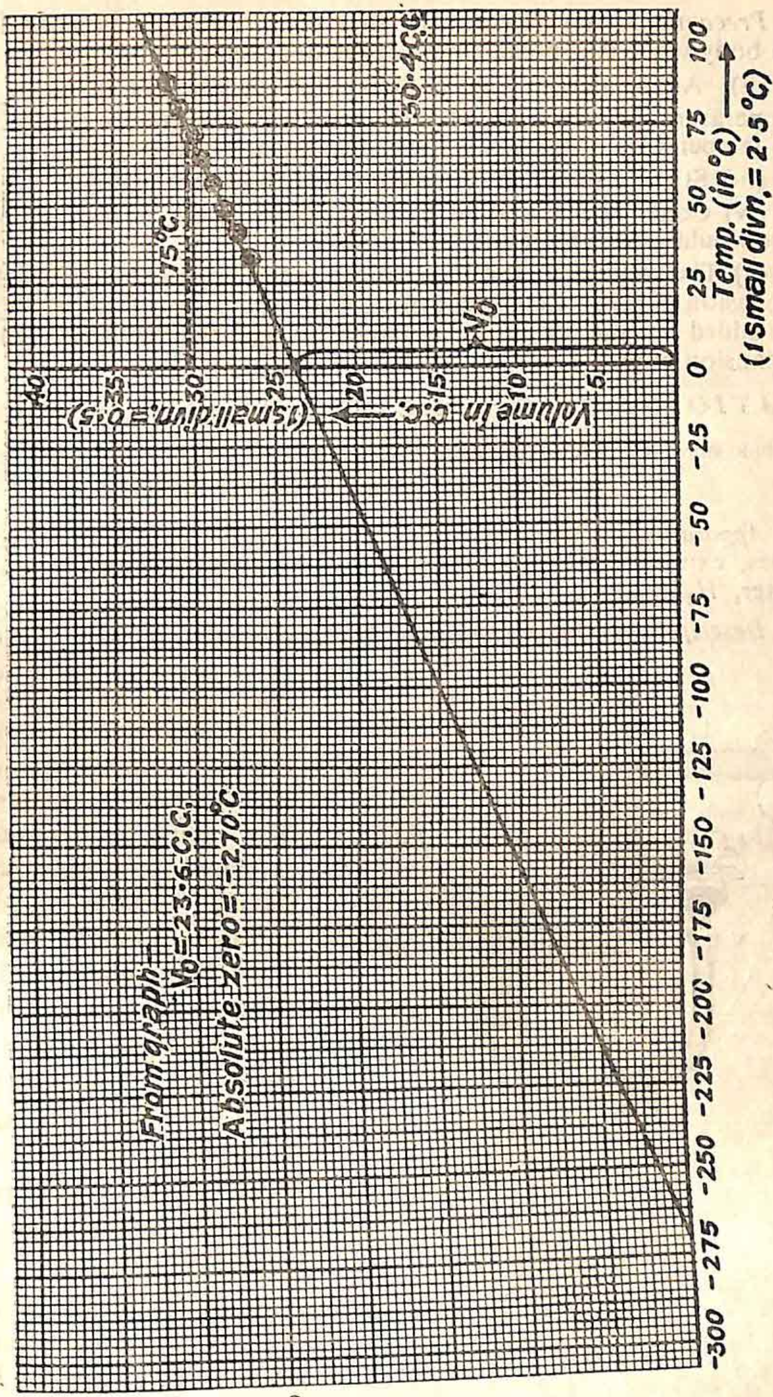
At 75°C $V_{75} = 30{\cdot}4$ c.c.

$$\gamma_y = \frac{V_{75} - V_0}{V_0 \times 75} = \frac{30{\cdot}4 - 28{\cdot}6}{23{\cdot}6 \times 75} = \frac{6{\cdot}8}{1770}$$

$$= 0{\cdot}003854 \text{ per °C}$$

Standard value $= 0{\cdot}00367$ per °C.

% error $= 5{\cdot}01\%$.


Temp. (in °C) →
(1 small divn. = 2·5 °C)
-300
-275
-250
-225
-200
-175
-150
-125
-100
-75
-50
-25
0
25
50
75
100
Volume in c.c. →
(1 small divn. = 0·5)
5
10
15
20
25
30
35
40
75°C
30·4 C.C.
V0
From graph—
V0=23·6 C.C.
Absolute Zero=-270°C

(Fig. 2.30)

Precautions. (i) Take care that conc. H_2SO_4 may not fall on the body while it is poured in the tube or taken away.

(ii) As the air and glass both are bad conductors of heat, the temperature of the bath should be raised gradually to ensure that the temperature of the gas is the same as that of the bath.

(iii) Stirring should be done constantly and thoroughly.

(iv) Conc. H_2SO_4 should be used otherwise the pressure of moisture would affect the result very much.

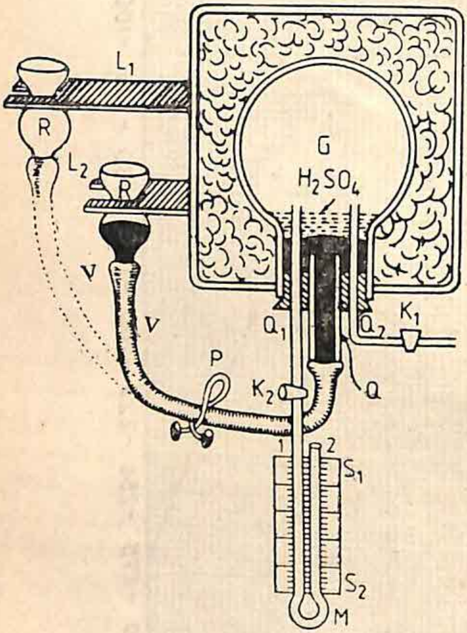
(v) The value of γ_p thus determined is the apparent coefficient of expansion of gas. Coefficient of cubical expansion of glass should be added to the value so obtained to get the real coefficient of expansion of gas.

RATIO OF TWO SPECIFIC HEATS OF A GAS

EXPERIMENT 13. Determination of the ratio of two specific heats (γ) of a gas by Clement and Desormes' method.

Apparatus. A wooden vessel, a glass vessel, rubber cork, three tubes, experimental gas, mercury, thermometer, barometer, manometer, H_2SO_4.

Description of the apparatus. A glass vessel G is kept inverted in a wooden box W and the space between the glass vessel G and wooden-box W is filled up with non-conducting material. The mouth of the vessel is closed by a rubber-cork having three holes through which passes three tubes Q_1, Q_2 and Q. M is a manometer which contains light oil and is connected to the tube Q_1. With the help of scale S_1S_2, the difference of liquid levels in the two arms of manometer is calculated. The tube Q_2 is connected to the reservoir of the experimental gas through stop-cock K_1. The tube Q is wide open



(Fig. 2.31)

and is connected to the mercury reservoir R with the help of a rubber tube V which can be closed by a pinch-cock P The tube Q_1 connected to the manometer M has been enclosed with a stop-cock K_2. The slotted shelves L_1 (upper) and L_2 (lower) have been attached with the box W in such a way that the neck of the reservoir R is arrested inside the slots. Some mercury is placed in the vessel G above the cock in such a way that the depth of this mercury is nearly 1 cm when the reservoir R is at lower shelf L_2. In order to keep the experimental gas dry, some sulphuric acid is introduced above the mercury through the stop-cock K_1.

Theory. The ratio (γ) of the two specific heats of the gas is given by the expression

$$\gamma=\frac{\log p_1-\log B}{\log p_2-\log B} \quad .. (1) \text{ [for adiabatic compression]}$$

$$\text{or } \gamma=\frac{\log B-\log p_1}{\log B-\log p_2} \quad .. (2) \text{ [for adiabatic expansion]}$$

where p_1 is the pressure (in gm-wt.) of a fixed amount of gas immediately after adiabatic compression (or expansion) and p_2 is its pressure (in gm-wt.) when the gas attains room-temperature after adiabatic compression (or expansion). B is the atmospheric pressure and measured as $B=H\times 13{\cdot}6$ gm wt. if H cm of mercury be the Barometric height.

Procedure. (i) Determine the sp.gr. ρ of manometric liquid with respect to water at 4°C with the help of a sp. gr. bottle. Then find out the Barometric height H cm of Hg to get the atmospheric pressure $B=H\times 13{\cdot}6$ gm wt. Place the mercury reservoir R at the lower shelf L_2. Open the stop-cock K_1 and allow the experimental gas in vessel G (which should be kept vacuum unless the gas is air) at atmospheric pressure. Allow the gas to remain undisturbed for few minutes to attain the room-temperature. Now observe the two arms of manometer after opening the stop-cock K_2 and pinch-cock P such that the liquid levels in two arms of manometer lie in the same horizontal plane.

(ii) Close the stop-cock K_2 and pinch-cock P. Now raise the reservoir R to the upper shelf L_1 and open P and K_2 both so that mercury in reservoir R will now enter G and compress the gas in it adiabatically causing a rise of temperature and pressure. Watch till the liquid level in the arm 1 of Manometer is depressed to a minimum level and attains a steady state after few oscillations. Now close the stop-cock K_2 and the pinch-cock P.

(iii) Shift the reservoir R again to lower shelf L_2. Open the pinch-cock P to bring mercury back to R from G. Now watch till the gas in G attains room-temperature. Afterwards close the pinch-cock P and bring back the reservoir R to the upper shelf L_1. Again open the pinch-cock P so that mercury from R moves to G. Close the stop-cock K_2 after the completion of re-entry of mercury from R to G. It will appear in the experiment that the depressed level of liquid in arm 1 of manometer M remains practically at the same level as before. Note down the maximum difference of liquid levels in the arms 1 and 2 of manometer. Say, it is h_1 cm Hence $p_1=(h_1\rho+B)$ gm-wt.

(iv) Allow the gas in this compressed state to stand for some time by keeping P and K_2 open. The gas will return to room-temperature. The depressed liquid level in arm 1 will rise to some extent. When the liquid levels in the two arms 1 and 2 of manometer are steady, note down the difference of liquid levels (h_2 cm). Hence $p_2=(h_2\rho+B)$ gm-wt. at room-temp. As p_1, p_2 and B are known, the value of γ is calculated.

Repeat the operations (ii) to (iv) thrice and calculate γ in each case and then determine the mean value of γ.

(v) Repeat the experiment in the above manner by filling the vessel G with the experimental gas when the reservoir R is kept at the upper shelf L_1. Now lower the reservoir R to the lower shelf L_2 so that the gas may perform adiabatic expansion. In this state note down its pressure p_1. When the gas attains room temp. by accepting heat from surroundings the pressure p_2 is also noted. As p_1, p_2 and B are known, obtain γ from the relation (2). Repeat this process thrice and get the mean value of γ. The mean of the two mean values of γ (one during adiabatic compression and another during adiabatic expansion) gives the true value of γ for the experimental gas.

Observations and Calculations

(A) *Determination of the sp. gr.* (ρ) *of Manometric Liquid.*

Room temperature $= t°\text{C} = \ldots.°\text{C}$.

No. of obs.	Wt. of clean sp.gr. bottle +water at $t°\text{C}=(w_1)$	Wt. of dry and empty bottle$=(w_2)$	Wt. of bottle +liquid $=(w_3)$	Density of water at $t°\text{C}$ $=(\rho t)$	$\rho=\frac{w_3-w_2}{w_1-w_2}\times\rho t$
1					
2					
3					

(B) *Determination of the Barometric Height* (*H* cm).

. . . .v.d. = ...s.d.

∴ v.c. = ...s.d. = ...cm.

	Main scale readings in cm (S).	Vernier readings in cm (V)	Total reading in cm $=S+V$	Mean H in cm	Atmospheric pressure $=B$ $=H\times 13{\cdot}6$ gm-wt.
Before Expt.					
After Expt.					

(C) *Determination of* γ *by Adiabatic compression.*

Instant of noting manometer	No. of observations	Reading in cm. of the two arms of manometer				Pressure in gms-wt. $=p=B+h\rho$	$\log p-\log B$	$\gamma_1=\dfrac{\log p_1-\log B}{\log p_2-\log B}$
		Arm no. 1 R_1	Arm no. 2 R_2	Diff. $=h$ $=(R_2\sim R_1)$	Mean h			
Just at the end of adiabatic compression	1	....	....	....		$p_1=B+h\rho$ =.....	$\log p_1-\log B$ =.....	
	2	....	....	....	...$=h_1$			
	3	....	....	....				
When the adiabatically compressed gas attains room temp.	1	....	....	....		$p_2=B+h_2\rho$ =.....	$\log p_2-\log B$ =.....	
	2	....	....	....	...$=h_2$			
	3	....	....	....				

(D) *Determination of* γ *by adiabatic expansion.*

Instant of noting Manometer	No. of. observations	Reading in cm. of the two arms of manometer				Pressure in gm-wt. $=p=B-h\rho$	$\log B-\log p$	$\gamma_2=\frac{\log B-\log p_1}{\log B-\log p_2}$
		Arm no. 1 R_1	Arm no. 2 R_2	Diff. $=h$ $=(R_1-R_2)$	Mean			
Just at the end of adiabatic expansion	1	....	....	....		$p_1=B-h_1\rho$ $=......$	$\log B-\log p_1$ $=.....$	
	2	....	....	....	$...=h_1$			
	3	....	....	....				
When the adiabatically expanded gas attains room temp.	1	....	....	....		$p_2=B-h_2\rho$ $=...$	$\log B-\log p_2$ $=......$	
	2	....	....	....	$...=h_2$			
	3	....	....	....				

True value of $\gamma=\frac{\gamma_1+\gamma_2}{2}=\ldots.$

Standard value = ...
% of error = ...

Precaution. (i) In order to get the correct positions of liquid levels in the arms of manometer one should note down the difference of liquid levels in the two arms of manometer when the oscillations of its liquid subsides. As such procedure should be such as to record the maximum difference of liquid levels in manometer without its oscillations when the adiabatic compression or expansion has just come to an end.

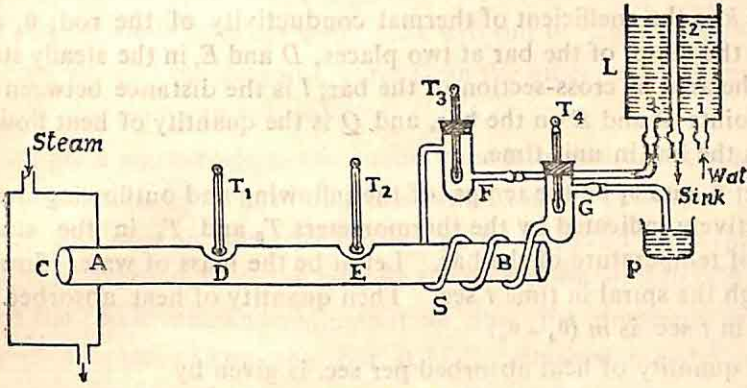
(ii) Allow the experimental gas to remain undisturbed until it assumes room temp. after each adiabatic compression or expansion.

(iii) The gas in the vessel G should not be compressed with such a force as to blow out some manometric liquid.

CONDUCTIVITY OF A SOLID

EXPERIMENT 14. **Measurement of thermal conductivity of a metal by Searle's method.**

Apparatus. Searle's apparatus for conductivity of metals, 2 thermometers reading $\frac{1}{2}$°C (ordinary thermometers) and 2 sensitive thermometers reading $\frac{1}{5}$°C, boiler for generating steam, constant head water flow arrangement, slide callipers, beaker, balance and stopwatch.



(Fig. 2.32)

Description of the apparatus. SEARLE'S APPARATUS : It consists of a thick polished bar *AB* of copper about 30 cm in length, 3-4 cm in diameter. It is covered with dry felt and enclosed in a wooden box. A chamber *C* is fitted at the end *A* of the rod in which steam can be passed to heat the rod. Near the other end of the bar *AB* a spiral *S* of thin copper tubing is soldered and a steady flow of water is maintained through it from a constant head apparatus. The constant head apparatus consists of a cylindrical can provided with three tubes —one for the inlet (1), one for the const. head (2) and third for the connection of side tube *F*. The can should be placed at a convenient height during the experiment. The inflow should be faster than the outflow. Excess water goes to the sink through (2). The temp. of the incoming water and that of outflowing water is measured by the thermometers T_3 and T_4 introduced in the tubes *F* and *G* respectively. The water enters the spiral tube *S* from a constant level water head *L*. Two other thermometers T_1 and T_2 are introduced into mercury contained in two holes *D* and *E* drilled in the rod at a distance of nearly 10 cm. between them. Mercury is placed in the holes to ensure good thermal contact. The whole piece of the apparatus is felt-lined and covered in a wooden case with a removable front to prevent loss of heat from radiation. The outgoing water is collected in a beaker P as shown in the diagram.

Theory. Let us suppose that a steady temperature is maintained along a bar of cross-section A. Then heat flowing per sec. will be given by :

$$Q = kA\frac{\theta_1-\theta_2}{l} \quad \text{.. (1)}$$

where k is the coefficient of thermal conductivity of the rod; θ_1 and θ_2 are the temp. of the bar at two places, D and E, in the steady state; A is the area of cross-section of the bar; l is the distance between the two points D and E on the bar, and Q is the quantity of heat flowing across the bar in unit time.

Let θ_3 and θ_4 be the temps. of the inflowing and outflowing water respectively indicated by the thermometers T_3 and T_4 in the steady state of temperature of the bar. Let m be the mass of water flowing through the spiral in time t sec. Then quantity of heat absorbed by water in t sec. is $m\ (\theta_4-\theta_3)$. .. (2)

So quantity of heat absorbed per sec. is given by

$$\frac{m(\theta_4-\theta_3)}{t} \quad \text{.. (3).}$$

$$\therefore \quad kA\frac{\theta_1-\theta_2}{l} = \frac{m(\theta_4-\theta_3)}{t}$$

$$\therefore \quad k = \frac{lm(\theta_4-\theta_3)}{At(\theta_1-\theta_2)}$$

$$= \frac{m}{t} \cdot \frac{l}{A} \cdot \frac{\theta_4-\theta_3}{\theta_1-\theta_2} \quad \text{.. (4).}$$

Procedure. (i) Fill two-thirds of the boiler with water and place it on tripod stand. Apply one or two burners below it to produce steam. But, do not connect the boiler to the steam inlet of the apparatus at this stage. Carry out other operations while the steam is being formed.

(ii) Open the box and measure the diameter of the rod at different places with the slide callipers. Take their mean. Also measure the distance between the centres of the holes D and E by a scale or by a divider and a scale. Weigh out the empty beaker correct to a centigram.

(iii) Put some mercury in the holes D and E. Then place the bulbs of the thermometers T_1 and T_2 (of 100°C each) and T_3 and T_4 (of 50°C each) at their respective positions carefully, but tightly. Close the box and connect the boiler to the inlet of the steam chamber by a short rubber tube and pass a steady current of steam into it. Lead the exhaust steam into a suitable vessel having some water in it.

(iv) On the other end of the rod connect one end (inlet) of copper spiral to the constant water head tap No. (3) by a rubber tube. The outflowing water from the water tank will run to sink. During this interval of time the outgoing water from the other end of spiral S should also lead into the sink.

Apply a pinch-cock on the rubber tube joining the inlet of spiral S and outlet of constant head apparatus and close this pinch-cock. Allow water to enter in the tank through its inlet (1) and when the water begins to overflow from the tank to the sink through outlet (2), then open the pinch-cock and regulate it so that the outgoing water is 5 c.c. per sec. (You can test it with a stop-watch and a graduated cylinder though not necessary). The rubber corks in the tubes F and G with thermometers T_3 and T_4 should be tightly fitting so that the leakage of water through them is avoided.

(v) Adjust the height of the constant head apparatus and the rate of outflow of water through the spiral tube such that the temp. differences between the outgoing and incoming water is maintained at about 10°C.

(vi) Temp. of each portion of rod would be indicated by the thermometers T_1 and T_2. Note down the temp. of all the thermometers at intervals of 3 to 4 minutes till the readings of thermometers are found to be steady. After half an hour the steady state temperature of the rod will be reached, when the temp. θ_1 and θ_2 indicated by the thermometers T_1 and T_2 become constant. The temp. θ_3 and θ_4 will be constant in this steady state. When this state is achieved place the previously weighed beaker P under the exit tube and collect about 100 c.c. of water taking care to note the time of collection of this amount of water by a stop-watch.

(vii) Record the readings indicated by four thermometers. Find out the mass of collected water by weighing it. The diff. of final wt. of beaker with water and the initial wt. of empty beaker will give the mass of water collected in t sec.

(viii) Repeat the observations three times if time permits.

Observation and Calculation

(*A*) *Measurement of diameter.*

Least count of vernier callipers = 0·01 cm.

Zero error = 0.

S.N.	Diameter along one direction in cm (a)					Diameter along perp. direction in cm (b)					Mean $\frac{a+b}{2}$
	M.S.	V.R.	V.R.× L.C.	Total	Corrected	M.S.	V.R.	V.R.× L.C.	Total	Corrected	
1	3·6	5	0·05	3·65	3·65	3·6	7	0·07	3·67	3·67	3·66
2	3·6	3	0·03	3·63	3·63	3·6	5	0·05	3·65	3·65	3·64
3	3·6	5	0·05	3·65	3·65	3·6	5	0·05	3·65	3·65	3·65

Mean diameter (D) = 3·65 cm.

$$\therefore\quad A=\pi\left(\frac{D}{2}\right)^2=\pi\left(\frac{3{\cdot}65}{2}\right)^2=10{\cdot}46 \text{ sq. cm.}$$

(*B*) *Distance between Thermometers T_1 and T_2.*

$$l=\frac{10{\cdot}22+10{\cdot}20+0{\cdot}18+10{\cdot}22+10{\cdot}18}{5}=10{\cdot}20 \text{ cm.}$$

(*C*) *Time-Temp. record and calculation.*

Mass of empty beaker (w) = 100 65 gm.

S.N.	Time in min.	Reading of Thermometers in (°C)				$\theta_1-\theta_2$ (°C)	$\theta_4-\theta_3$ (°C)	Mass of beaker +water (w_1) gm	Mass of water $m=w_1-w$	Time of collection (t sec.)	Value of k	Mean value of k
		T_1	T_2	T_3	T_4							
I	0 4 8 28	84·2 (θ_1)	61·8 (θ_2)	27 (θ_3)	36·8 (θ_4)	22·4	9·8	369·19	268·54	123	0·9321	0·9298=0·930
II	0 4 8 28	85 (θ_1)	63·8 (θ_2)	27 (θ_3)	40·8 (θ_4)	21·2	13·8	276·08	175·43	120	0·9276	
III	0 4 8 28	(θ_1)	(θ_2)	(θ_3)	(θ_4)							

Result : $k=0{\cdot}930$ cal. per sec. per cm per °C.

Standard value of k (For copper) = 0·918 cal./sec /cm/°C.

% error = 1·3%

Precautions. (i) The diameters should be measured at a number of places. Both direct and cross readings should be taken.

(ii) To ensure steady state the temp. of all thermometers should give constant readings for at least three consecutive intervals.

(iii) To have an appreciable difference of temp. between the incoming and outflowing waters only a trickle of water must flow.

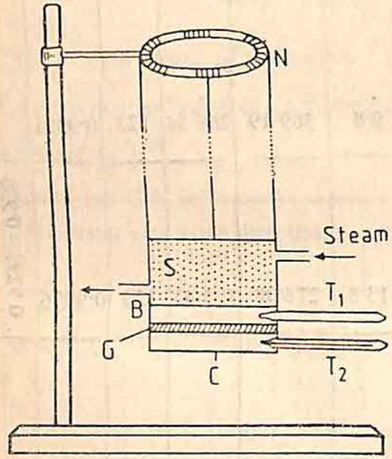
(iv) While collecting water in the beaker P, measure the temperatures θ_1, θ_2, θ_3, θ_4 at intervals of one minute and if any slight change appears in each thermometer take the mean of several temperatures during the intervals in which water is collected.

(v) Do not displace any part of outflowing rubber tube during the time of collection of water.

EXPERIMENT 15. Determination of the conductivity of glass by the method of Lees and Charlton.

Apparatus. Steam generator, Lees and Charlton's apparatus, two sensitive thermometers, vernier callipers and screw guage.

Description of apparatus. The apparatus is made up of a heavy retort-stand with clamp and metal ring N from which is suspended a cylindrical slab C made of brass or copper of diameter about 12·5 cm with the help of threads so that its top surface remains horizontal. A steam chamber S rests on the slab C. The bottom of the steam chamber S is made up of thick brass or copper block B in which a hole is bored for inserting a thermometer T_1. The experimental substance G in the form of a circular disc is sandwitched between the block B and the block C. The second thermometer T_2 is inserted in the hole of the block C as shown in the fig. 2.33.



(Fig. 2.33)

Theory. Let A be the area of cross-section of the experimental slab G and d be its thickness. Let θ_1 and θ_2 be the temperatures recorded by the thermometer T_1 and T_2 in the steady state. Then the heat transmitted through the slab per second be

$$Q = kA.\frac{\theta_1 - \theta_2}{d}$$

where k is the thermal conductivity [neglecting the heat lost by it (G) radially].

This Q (rate of flow of heat) is equal to the rate at which the heat is radiated from the curved surface and the bottom surface of the disc C. If the plate C is heated to a temperature about 10-12° above θ_2 and then allowed to cool with the specimen disc G above it, a cooling curve of the plate is plotted by noting its temperatre at regular intervals of time till the temperature falls to about 10-12°C below θ_2. From the cooling curve $\left[\frac{d\theta}{dt}\right]_{\theta=\theta_2}$ is calculated by drawing a tangent to the curve at the point corresponding to $\theta=\theta_2$. If m be the mass of the disc and s its specific heat, the heat lost per second by the disc C by radiation when at a temperature θ_2 is

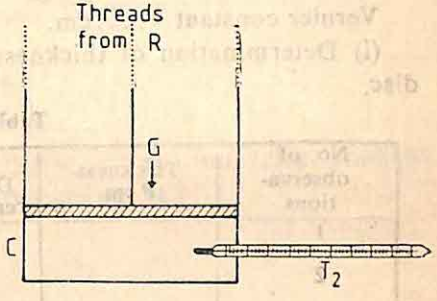
$$Q=ms\left[\frac{d\theta}{dt}\right]_{\theta=\theta_2}.$$

Hence,
$$\frac{kA(\theta_1-\theta_2)}{d}=ms\left[\frac{d\theta}{dt}\right]_{\theta=\theta_2}$$

$$\therefore\ k=\frac{dms\left[\frac{d\theta}{dt}\right]_{\theta=\theta_2}}{A(\theta_1-\theta_2)} \qquad \ldots (1).$$

Procedure. (i) Firstly weigh the plate C and find out its mass m. Measure the diameter of the experimental disc G with the help of slide callipers (Vernier callipers) three times and find out its mean diameter. Then calculate its radius r and the area of cross-section $A=\pi r^2$.

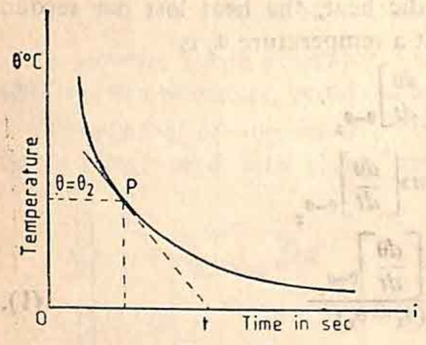
(ii) Calculate the temperatures θ_1 and θ_2 with the apparatus as shown in the Fig 2.34 with experimental disc G which is sandwitched between B and C. Allow the steam from steam-chamber to pass into the chamber S. Wait for about forty minutes and then record the temperatrues θ_1 and θ_2 as shown by T_1 and T_2 at a regular intervals of two minutes. It will be obvious from these observations whether the steady state has been achieved or not. When θ_1 and θ_2 become steady, note down these. Thus the first part of the experiment is complete.



(Fig. 2.34)

(iii) In order to determine $\left[\frac{d\theta}{dt}\right]_{\theta=\theta_2}$, heat the disc C alone separately with help of a Bunsen flame so that T_2 indicates a temperature about 10-12°C above θ_2 as observed during the steady state. Suspend C with help of threads attached to ring N with the experimental specimen G placed on the top of it. Allow it to cool down. Note down the temperature of the disc C at regular intervals of time (may be half a minute nearly) till the temperature falls to about 10-12°C below θ_2 (the temperature of C as recorded during steady state).

(iv) Plot the graph between the temperature θ and the time *t* and find out the cooling curve of the disc *C* as in fig. 2.35. Now draw the tangent to the curve at a point on the curve corresponding to $\theta=\theta_2$ and then determine the value of $\left[\frac{d\theta}{dt}\right]_{\theta=\theta_2}$. The specific heat *s* of the material of the disc *C* is supposed to be known. All the quantities involved in the equation (1) are known, hence *k* is calculated.



(Fig. 2.35)

Observation and Calculation

Mass of the disc $C=m$ gm.

Specific heat of the material of disc $=s$ cal/gm/C°.

Least count of screw guage = ...cm.

Vernier constant = ...cm.

(i) Determination of thickness '*d* and '2*r*' of the experimental disc.

Table 1

No. of observations	Thickness *d* cm	Diameter 2*r*		Mean cm
		Direct reading	Cross-reading	
1				
2				
3				
4				
5				

Table 2

No. of observations	Time in minutes	Reading of the thermometer in °C	
		T_1	T_2
1	0	...	...
2	2	...	...
3	4	...	...
4	6	...	...
5	8	...	...

Table 3

Readings for cooling curve of Disc C.

No. of observations	Time in seconds	Temperature of Disc C θ°C	No. of obs.	Time in seconds	Temp. of Disc C θ°C

Area of cross-section of the disc $(A) = \pi r^2$ sq. cm.

$\theta_1 = \ldots\ldots$°C.

$\theta_2 = \ldots\ldots$°C.

From the graph,

$$\left[\frac{d\theta}{dt}\right]_{\theta=\theta_2} = \ldots\ldots \text{°C per sec.}$$

$$\therefore \quad k = \frac{msd}{A(\theta_1 - \theta_2)} \times \left[\frac{d\theta}{dt}\right]_{\theta=\theta_2}$$

$= \ldots$ cal. per sec. per sq. cm per unit temp. gradient

$= \ldots$ cal. per sec. per cm per °C.

Standard value of $k = \ldots\ldots$

% error $= \ldots\ldots$

Precaution.

(i) The thermometers used should be sensitive to read up to $\frac{1}{10}$th of a degree Celsius.

(ii) The steady state achieved should be determined by noting the temperatures θ_1 and θ_2 at regular interval of time (i.e. every two minutes) and then observing that these temperatures do not change with time.

(iii) Carefully determine the constants of the experimental disc with the help of vernier and screw guage.

(iv) The disc employed in this experiment should be thin because it has been assumed that no heat is lost from the curved surface of the specimen.

(v) The disc C should be cooled with the specimen G above it.

(vi) In case the specimen G is not placed over the disc C and the disc is allowed to cool, then the exposed surface is increased and the equation (1) is modified as

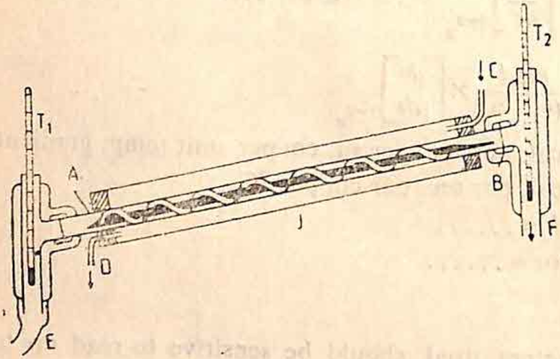
$$\frac{kA(\theta_1-\theta_2)}{d}=ms\left[\frac{d\theta}{dt}\right]_{\theta=\theta_2}\times\left(\frac{r+2l}{2r+2l}\right)$$

where r and l are the radius and the length of the cylindrical disc respectively.

EXPERIMENT 16. To determine the co-efficient of Thermal Conductivity of glass in the form of tube.

Apparatus. Glass-tube enclosed in a wider tube which forms the steam-jacket, graduated jar, two thermometers (reading up to $\frac{1}{5}$th °C), boiler for generating steam, constant head water flow arrangement, slide callipers and travelling microscope.

Description of apparatus. A hollow glass tube AB of bore about 1·5 cm enclosed in a wider jacket J. Steam is made to enter the jacket at C and leaves at D. Two T-pieces are joined to the tube AB one at each end with the help of short rubber tubing and each encloses a thermometer T_1 and T_2. A steady stream of water is allowed to pass across the tube with the help of a constant water-level tank which has not been shown in the figure. Now the temperatures at entrance and exit are measured with the help of two thermometers T_1 and T_2 respectively.



(Fig. 2.36)

The water is allowed to traverse the tube along a spiral path so that the temperature of water remains constant over any cross-section of the tube. It is achieved by winding a rubber spiral of a wide spacing over a thin brass rod and placing it within the experimental tube AB.

Theory. The heat flows radially from the outside surface of glass to its inner surface if the steam is allowed to pass through the jacket and the isothermal surfaces are co-axial cylinders. Let θ_1 and θ_2 be the temperatures of the outer and inner surfaces of glass-tube in the steady state. Thus the amount of heat flowing across its walls per sec is given by

$$Q=\frac{2\pi kl(\theta_1-\theta_2)}{2\cdot3026\,\log_{10}(r_2/r_1)}$$

where r_1 and r_2 are the internal and external radii of the glass tube, l its length and k is the co-efficient of conductivity of glass.

The amount of heat Q is obtained by the steady flow of water inside the tube. Let m gms per sec be the mass of water flowing at a constant rate and θ_3 and θ_4 be the temperatures of water at the entrance and exit in the steady stage. Then

$$Q=m(\theta_4-\theta_3).$$

Hence $$\frac{2\pi kl(\theta_1-\theta_2)}{2\cdot3026\,\log_{10}(r_2/r_1)}=m(\theta_4-\theta_3)$$

or $$k=\frac{2\cdot3026\,\log_{10}(r_2/r_1).m(\theta_4-\theta_3)}{2\pi l(\theta_1-\theta_2)}$$

where θ_1 is equal to the temperature of steam and the temperature θ_2 of the internal surface of glass tube can be taken to be equal to $\frac{\theta_3+\theta_4}{2}$ i.e. the average temperature of water inside the tube.

$$k=\frac{2\cdot3026\,\log_{10}(r_2/r_1).m(\theta_4-\theta_3)}{2\pi l\left[\theta_1-\dfrac{\theta_3+\theta_4}{2}\right]}.$$

Procedure. (i) Arrange the apparatus as shown in the fig. 2.36. Now allow the steady current of steam from the boiler to pass into the steam jacket J to heat the outer surface of the tube AB. Further it is essential to pass a steady stream of water to flow past the tube spirally. It enters the entrance end at P and leaves at Q. Arrange the glass tube in inclined position in order that the exit end may remain at a higher level than the inlet end. This process will have two advantages. Firstly, the tube will always remain filled with water and secondly any air evolved from the water owing to rise in temperature will be easily swept out. Adjust the rate of flow of water to be low so that a measurable difference of temperature between incoming and outgoing water through the tube may be achieved. Note down the temperatures θ_1 and θ_2.

(ii) Now it is essential to wait for some time to watch whether the steady state has been reached. This is obtained by recording the temperatures θ_3 and θ_4 every five minutes and noting that there is no change in their respective values. Final observations give the steady temperature θ_3 and θ_4.

(iii) Now our purpose is to determine the rate of flow of water. For this purpose, collect water in a graduated jar and note down the time for which the water is collected. As the density of water is unity and the time is known, the rate of flow of water can be calculated. Repeat it a number of times and calculate the mean value of *m*. Observe the barometric height *H* and calculate the tempeature of steam θ_2 from the tables.

(iv) Now measure the length *l* of the glass tube exposed to steam. Further measure the external diameter of the tube at a number of places with a slide calipers. At evry place measurement should be made along two mutually perpendicular diameters and obtain the mean external radius r_2. In order to find the mean values of r_1, insert a cork tightly at one end of the tube and clamp it vertically. Fill a known volume of water into the tube with the help of a burette. Measure the height of water column in the tube. Let *V* be the volume of water and *b* be its height.

Then
$$\pi r_1^2 b = V$$

or
$$r_1 = \sqrt{\frac{V}{\pi b}} \quad \ldots \quad (1)$$

As all the quantities involved in the equation (1) for the determination of *k* are evaluated, *k* can be known. The experiment is repeated by changing the rate of flow of water and the mean value of *k* is obtained.

Observation and Calculations

(A) *Reading of Barometer* = *H* cm *of Hg.*

The temperature of steam corresponding to the reading of the Barometer = θ_1°C.

Steady temperature of water at the entrance of the tube $=\theta_3$°C.

Steady temperature of water at the exit of the tube $=\theta_4$°C.

∴ Temperature of the inner surface of the tube

$$=\theta_2=\frac{\theta_3+\theta_4}{2}\,^\circ\text{C}.$$

Length of the glass tube exposed to steam $=l$ cm.

(B) *Determination of external diameter of the tube.*

Least current or Vernier constant of slide callipers = ...cm.
zero error = ...cm.

No. of Obs.	Reading along one diameter (a) cm					Reading along perpendicular diameter					Mean
	M.S.	V R.	V.R. × L.C.	Total	Corrected reading	M.S.	V.R.	V.R. × L.C.	Total	Corrected reading	D

∴ Diameter $=D$.

∴ radius $=\frac{D}{2}$.

(C) *Determination of internal radius of the tube.*

Least count of the travelling microscope = ...

No. of Obs.	Height of water column (cm)							Volume of water taken in V cc	$r_1=\sqrt{V/\pi b}$
	Lower			Upper			Difference		
	M.S.	V.R.	Total	M.S.	V.R.	Total			
1									
2									
3									

(D)

No. of Obs.	Mass of beaker $=(M)$ gm	Beaker + water $=(W)$ gm	Mass of water collected $=(W-M)=m$ gm	Time for collection of water $=t$ (sec)	Rate of flow of water
1	M	W_1	(W_1-M)	t_1	...
2	M	W_2	(W_2-M)	t_2	...
3	M	W_3	(W_3-M)	t_3	...
4	M	W_4	(W_4-M)	t_4	...
5	M	W_5	(W_5-M)	t_5	...

$$\therefore \quad k=\frac{2{\cdot}3026 \log_{10}(r_2/r_1).m(\theta_4-\theta_3)}{2\pi l t\left[\theta_1-\dfrac{\theta_3+\theta_4}{2}\right]}.$$

Result. Conductivity of glass = ... cal./sec./cm²/°C

Standard value = ...

∴ % error = ...

Precaution. (i) The length of the tube exposed to shade should be measured and used in calculations. This will be the length inside the jacket.

(ii) Water should be made to flow from a constant level arrangement and not from the tap.

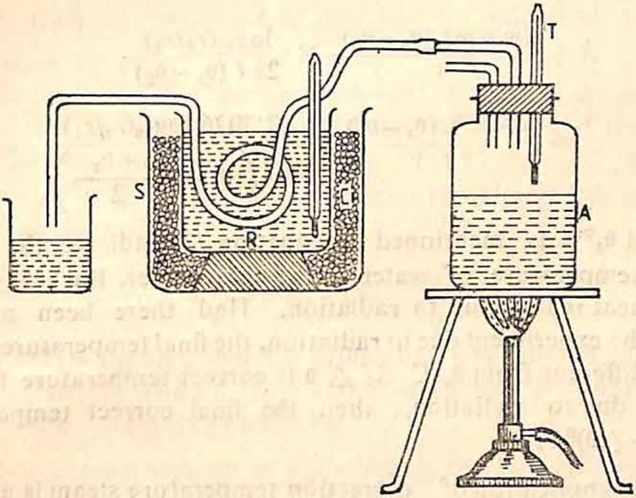
(iii) The rate of flow of water should be low.

(iv) The water should traverse the tube spirally and along an up gradient of height.

EXPERIMENT 17. Determination of co-efficient of thermal conductivity of rubber-tube.

Apparatus. Rubber-tube, steam boiler, Bunsen burner, stop-watch, balance, big calorimeter, sensitive thermometers, callipers and microscope.

Description of Apparatus and Theory. A is a boiler as shown in the figure 2.37. Immerse a Known length l of the rubber tube in the water of calorimeter *C*. One end of the tube is connected to the boiler *A* and the other end remains outside the calorimeter. The steam passes through this tube. The temperature of the water and the calorimeter increases as the steam passes through the rubber tube. After some time the flow of steam is stopped and the time for which the steam passed through the tube is noted. Correction is applied in final temperature of calorimeter and its water on account of loss of heat due to radiation. The internal and the external radii of the tube are determined either with the help of callipers or with the help of ink-imprint of the area of cross-section and microscope.



(Fig. 2.37)

Let *m* be the mass of water in calorimeter and *w* be the water equivalent of calorimeter. Let the temperature of water in calorimeter increase from θ_3°C to θ_4°C in *t* sec.

Hence the amount of heat Q lost per sec by the rubber tube

$$Q=\frac{(m+w)\ (\theta_4-\theta_3)}{t}$$

where as from the consideration of co-efficient of thermal conductivity

$$Q=\frac{2\pi kl\,(\theta_1-\theta_2)}{\log_e(r_2/r_1)}$$

where k is the co-efficient of thermal conductivity of rubber-tube, r_1 is the internal radius and r_2 the external radius of the rube. Let the observed reading of the steam as recorded by thermometer T

inserted in the boiler A be θ_1°C, θ_2°C be the average temperature of outer surface of the tube = average temperature of calorimeter.

$$\therefore \quad \frac{2\pi kl\,(\theta_1-\theta_2)}{\log_e(r_2/r_1)}=\frac{(w+m)\,(\theta_4-\theta_3)}{t}$$

or

$$k=\frac{(w+m)\,(\theta_4-\theta_3)}{t}\times\frac{\log_e(r_2/r_1)}{2\pi l\,(\theta_1-\theta_2)}$$

$$=\frac{(w+m)\,(\theta_4-\theta_3)}{t}\times\frac{2{\cdot}3026\,\log_{10}(r_2/r_1)}{2\pi l\left(\theta_1-\dfrac{\theta_3+\theta_4}{2}\right)} \quad \cdot\cdot \quad (1)$$

θ_3°C and θ_4°C as mentioned in equation (1) indicate the initial and final temperature of water in the calorimeter. But it is known that some heat is lost due to radiation. Had there been no loss of heat in the experiment due to radiation, the final temperature would have been different from θ_4°C If $\triangle\,\theta$ is correct temperature for the loss of heat due to radiation, then the final correct temperature will be $(\theta_4+\triangle\theta)$°C.

For the application of correction temperature steam is allowed to flow through the tube when the temperatere increases from θ_3° to θ_4°C. Temperature is noted at the interval of every half minute. Let these readings be $t_1, t_2, t_5, \ldots t_{n-1}$.

If the room temperature be t_0°C, then the changed temperature due to loss or gain of heat according to Newton's law of cooling will be

$$\delta\theta_1=C\left(\frac{\theta_3+t_1}{2}-t_0\right)$$

$$\delta\theta_2=C\left(\frac{t_1+t_2}{2}-t_0\right)$$

$$\delta\theta_3=C\left(\frac{t_2+t_3}{2}-t_0\right)$$

$$\cdots\cdots\cdots\cdots\cdots\cdots$$

$$\cdots\cdots\cdots\cdots\cdots\cdots$$

$$\cdots\cdots\cdots\cdots\cdots\cdots$$

$$\cdots\cdots\cdots\cdots\cdots\cdots$$

$$\delta\theta_n=C\left(\frac{t_{n-1}+\theta_4}{2}-t_0\right)$$

where $\delta\theta$ represents the change of temp. during any interval of time.

$$\text{Thus, } \triangle\theta = \Sigma\delta\theta = C\left\{\frac{\theta_3+\theta_4}{2} - nt_0 + (t_1+t_2+\,..\,+t_{n-1})\quad\right\},$$

where C is a constant and is dependent on calorimeter and its content. In order to calculate $\triangle\theta$, one has to determine the value of C also.

After knowing the final temperature θ_4°C in the experiment, stop the flow of steam. Allow the calorimeter to cool and during the process of cooling note down the temp. T_1, T_2, $T_3 \ldots . T_n$ at equal, interval of time. If like alove, $\triangle\theta'$ represents the changed temperature due to loss of heat, then

$$\triangle\theta' = \Sigma\delta\theta' = C\left\{\frac{T_1+T_n}{2} - (n-1)t_0 + (T_2+T_3+\,..\,+T_{n=1}\right\}$$

As $\Sigma\delta\theta' = T_1 - T_n$, so C can be calculated. It should be noted that during fall or rise of temp. the temperature range should remain the same as far as practicable.

Hence the corrected form of equation (1) can be written as

$$k = \frac{(w+m)\,(\theta_4+\triangle\theta-\theta_3)}{t} \times \frac{2{\cdot}3026\,\log_{10}(r_2/r_1)}{2\pi\, l\left(\theta_1 - \dfrac{\theta_3+\theta_4}{2}\right)} \quad .. \quad (2)$$

Procedure. (i) Take a calorimeter of capacity 1000 c.c. Clean and dry it. Weigh it along with stirrer with the help of balance. Fill two-third volume of the calorimeter with water and then weigh it again. A long part of the rubber tube should be in the form of spiral and immersed in the water of the calorimeter in such a way that both ends of rubber tube may remain just above the surface of the water in the calorimeter.

Tie thread knots at two places in the rubber tube i.e. one at the point where the tube just enters the water and the other at just the tube leaves the water in the calorimeter. These thread knots will work as indicator and the length of the tube between the two thread knots will be the length of the tube which will be measured at the end of experiment. Note down the temperature of water in the calorimeter.

(ii) Heat the water in the boiler with the help of Bunsen burner and allow the steam to flow out from the boiler. When the rate of formation of steam is uniform and steady, connect one end of the rubber tube (i.e. R in the fig.) with the boiler so that steam may flow out through the tube. Now place the other end of the rubber tube in some beaker or sink so that the steam coming out of the tube may condense there.

(iii) The moment the steam starts passing through the rubber tube, stir the water in the calorimeter with the help of steam and start noting down the temperature of water at the interval of every half minute. Disconnect the rubber tube from the boiler the moment the temperature of water rises by 10-15°C above the room temperature so that flow of steam is stopped. Stir the water well and start again noting down the falling temperature at the interval of every half minute. This should continue for nearly 7-8 minutes.

(iv) Measure the length of rubber tube between the two thread knots with the help of a metre scale. Put some ink on the surface of the one end of the tube and obtain an ink-imprint of the area of cross-section of the tube on a paper. Now measure the internal and the external radii of the tube with the help of microscope.

(v) Note down the temperature of the thermometer inserted in the boiler and this gives temperature of the steam. If there is no provision for inserting a thermometer in the boiler, then in that condition take the reading of the barometer that gives the atmospheric pressure. Now obtain the reading for the temperature of steam or boiling point of water corresponding to the this reading of the atmospheric pressure from the table. Hence co efficient of thermal conductivity of rubber can be calculated.

Observation and Calculations

Room temperature = 21·9°C

Mass of calorimeter + stirrer = (M) = 166·655 gm.

Mass of (calorimeter + stirrer + water) = 28·800 gm

∴ Mass of water m = 115·145 gm.

Initial temperature (θ_3) of water in calorimeter and its content = 22·7°C.

Time (t) for flow of steam = 5 mt. 30 sec. = 330 sec.

Length (l) of rubber tube immersed in the water of calorimeter $= 18{\cdot}13$ cm.

Outer radius (r_2) of the tube $= 0{\cdot}589$ cm.

Inner radius (r_1) of the tube $= 0{\cdot}304$ cm.

Reading of Barometer $= 748{\cdot}25$ mm.

$\therefore$ Corrected temperature of steam (θ_1)

$$= \left(100 - \frac{760 - 748{\cdot}25}{26{\cdot}8}\right) {}^\circ\mathrm{C} = 99{\cdot}56^\circ\mathrm{C}$$

[There is a change of 1°C due to 26·8 mm of *Hg*.]

Time-Temperature

Interval of time in minutes	Temp in °C	Interva' of time in minutes.	Temp. in °C
... ...	22·7 (θ_3)	7·5—8·0	33·1 ...(T_1)
0—0·5	23·7 (t_1)	8·0—8·5	33·0
0·5—1·0	24·8 (t_2)	8·5—9·0	32·9
1·0—1·5	26·0 (t_3)	9·0—9·5	32·8
1·5—2·0	27·0	9·5 10·0	32·8
2·0—2·5	28·0	10·0—10·5	32·7
2·5—3·0	29·1	10·5—11·0	32·6
3·0—3·5	30·0	11·0—11·5	32·5
3·5—4·0	31·0	11·5—12·0	32·5
4·0—4·5	31·8	12·0—12·5	32·4
4·5—5·0	32·8 (t_{n-2})	12·5—13·0	32·3
5·0—5·5	33·4 (t_{n-1})	13·0—13·5	32·2
5·5—6·0	33·4...(θ_4)	13·5—14·0	32·1 ...(T_n)
6·0—6·5	33·4	14·0—14·5	32·0
6·5—7·0	33·2	14·5—15·0	32·0
7·0—7·5	33·2		

Loss of heat due to radiation at the time of increase of temperature

$$= \triangle\theta = C\left\{\frac{\theta_3 + \theta_4}{2} - nt_0 + (t_1 + t_2 + \ldots . + t_{n-1})\right\}$$

where C is a constant and t_0 is the room temperature.

$$\therefore \quad \triangle\theta = C\left\{\frac{22{\cdot}7 + 33{\cdot}4}{2} - 12 \times 21{\cdot}9 + (22{\cdot}7 + 23{\cdot}7 + \ldots . + 33{\cdot}4)\right\}$$

$$= C\,\{28{\cdot}05 - 262{\cdot}8 + 306{\cdot}9\}$$

$$= C \times 72{\cdot}15 \qquad \ldots \quad (3).$$

Change in temp. during loss of heat in fall of temp. from T_1 to T_n

$$=\triangle\theta'$$

i.e.

$$\triangle\theta'=1°\text{C}=C\left\{\frac{T_1+T_n}{2}-(n-1)t_0+(T_1+T_2+\ldots+T_{n-1})\right\}$$

$$=C\left\{\frac{33\cdot1+32\cdot1}{2}-12\times21\cdot9+(33\cdot0+32\cdot9+\ldots\ldots+32\cdot2)\right\}$$

$$=C(32\cdot6-226\cdot8+358\cdot9)$$

$$=C\times128\cdot5$$

$$\therefore\quad C=\frac{1}{128\cdot5}.$$

Hence, $\triangle\theta=C\times72\cdot15=\frac{72\cdot15}{128\cdot5}=0\cdot5614°\text{C}.$

Therefore maximum corrected temperature of water after flow of steam

$$=\theta_4+\triangle\theta=(33\cdot4+0\cdot5614)°\text{C}=33\cdot9614°\text{C}.$$

Water equivalent of (calorimeter + stirrer) $=w$

$$=166\cdot655\times0\cdot094=\mathbf{15\cdot69}\text{ gm.}$$

Hence conductivity of rubber

$$k=\frac{(115\cdot145+15\cdot69)\,(33\cdot9614-22\cdot7)}{330}\times\frac{2\cdot3026\times\log_{10}\frac{0\cdot589}{0\cdot304}}{2\times\frac{22}{7}\times18\cdot13\times\left(99\cdot56-\frac{22\cdot7+33\cdot4}{2}\right)}$$

$$=\frac{130\cdot835\times11\cdot2614\times7\times2\cdot3026\times0\cdot2872}{44\times330\times71\cdot51\times18\cdot13}$$

$$=0\cdot000362\text{ cal/cm/sec/°C}.$$

Standard value of $k=0\cdot00035$ cal/cm/sec/°C.

∴ % error $=3\cdot43\%$.

Errors and Precaution. (i) The calorimeter should be of large capacity so that sufficient length of rubber tube can be placed in the water of calorimeter.

(ii) Thickness of rubber tube should be uniform.

(iii) Internal and external radii of rubber tube should be measured carefully.

(iv) Thread knots should be tied in such a way that they just touch the surface of water placed in calorimeter.

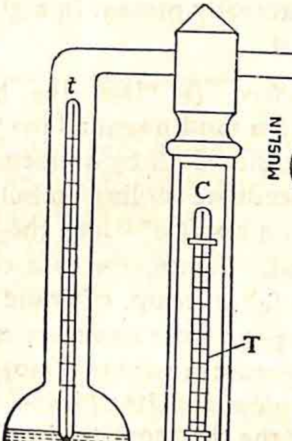
(v) The steam should be allowed to pass till such time the temperature of water just rise nearly 10-15°C.

HYGROMETRY

EXPERIMENT 18. To determine the relative humidity of air by Daniell's Hygrometer.

Apparatus. Daniell's Hygrometer, small pipette, ether and thermometer.

Description of the apparatus. DANIELL'S HYGROMETER : It consists of two glass bulbs *A* and *B* connected together by means of a wide glass tube, bent twice at right angles and mounted on a vertical stand. The bulb *A* contains ether with a thermometer (*t*) dipping into it. The bulb *A* is silvered. The bulb *B* with the tube connected to it is full of ether vapour. The air from the tube has been expelled before the tube is sealed. Bulb *B* is warpped round by a piece of muslin. A thermometer (*T*) is placed on the stem *C* to indicate the temp. of air.



(Fig. 2·38)

Theory. The hygrometric state of the air can be determined by knowing the amount of water vapour present in the atmosphere. But in the meteorological work, the idea of degree of saturation is more important than the actual amount of water vapour present. This is known as Relative Humidity and is defined as :

$$\frac{\text{The amount of water vapour actually present in a given volume of air at } t^\circ\text{C}}{\text{Amount of water vapour required to saturate the same vol. of air at } t^\circ\text{C}} \quad \ldots \quad (1)$$

$$= \frac{\text{Pressure of water vapour actually present in the air at } t^\circ\text{C}}{\text{Pressure of water vapour necessary to saturate air at } t^\circ\text{C}} \quad \ldots \quad (2)$$

$$= \frac{\text{Saturation vapour Pressure } (f) \text{ at the dew point}}{\text{Saturation vapour pressure } (F) \text{ at the temp. } t^\circ\text{C of the air}} \quad \ldots \quad (3).$$

But relative humidity is expressed generally in terms of percentage.

Hence, the equation (1) or (3) can be multiplied by 100 to give the relative humidity in percentage.

Now f and F are determined from the Regnault's table, so experimentally it is the *dew point* which has to be determined.

Dew point. It is the temperature at which the mass of water vapour actually present in a given volume of air is just enough to saturate it.

Procedure. (i) Place the hygrometer properly on a table and then wrap a muslin around the bulb B. Pour some ether drop by drop on the muslin cloth by a pipette or a dropper. By taking up its latent heat it produces cooling on bulb B. The ether vapour inside B condenses as a result of which the pressure on the surface of ether in A is reduced. Hence, the rate of evaporation in bulb A increases resulting in fall of temp. of liquid in it and that of silver strip on it. In this way pour more and more ether on muslin B till a stage is reached when moisture present in atmosphere begins to condense on it in the form of dew and its shining surface becomes dimmer. Note the temp. of the thermometer just at the moment when the first film of dew appears.

(ii) Now, do not pour ether in muslin around B and if necessary remove the muslin from it. The rate of evaporation in A slows down as no ether now condenses in B. Hence reduction of pressure on the surface of liquid in A does not take place any more.

Thereby, the temperature of A together with the silver strip goes on rising and the dew-drops on it begin to disappear. Note the temp. of the thermometer just when the last drop of dew has disappeared from the silver strip. The mean of the two temperatures gives the correct dew point (θ) at that time.

Read the temp. of air on the different thermometers attached to the stem *C*.

Repeat the above operations several times and take the mean of temp. of appearance and disappearance of dew. Obtain the value of maximum pressure *f* and *F* corresponding to the dew point θ and room temperature *t* respectively from the table of constants (see appendix) and the ratio of *f*/*F* multiplied by 100 gives the relative humidity of the air.

No. of obs.	Dew point (θ°C)			Atm. temp. t°C	Mean t°C	f	F	.H.
	Appearance	Disappearance	Mean					$=\frac{f}{F}\times 100$

Result = ...%

Precautions. (i) The humidity in the neighbourhood may be affected by the breath of the experimenter and hence interpose a glass-screen between the hygrometer and experimenter.

(ii) Regulate the rate of cooling in *A* by pouring ether gradually with a pipette or dropper.

(iii) Avoid to perform this experiment near a sink or open window.

(iv) As the first film of dew appears in *A*, its silvered surface appears to be dim. But if the surface is touched with a twisted piece of paper, the presence of dew is easily detected. Adopt this method for detecting the appearance and disappearance of dew.

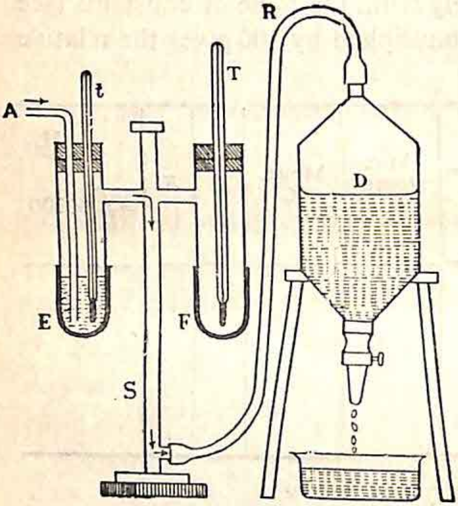
(v) Ether evaporating outside *B* contaminates the air and hence the hygrometric state of air is affected.

(vi) As glass is a bad conductor so temperature inside *A* is different from the temp. outside *A*.

EXPERIMENT 19. **To determine the relative humidity of air by Regnault's Hygrometer.**

Apparatus. Regnault's hygrometer, ether, aspirator, telescope.

Description of the apparatus. REGNAULT'S HYGROMETER: Regnault's hygrometer was designed to overcome the difficulties encountered in Daniell's hygrometer. It consists of a test tube having a side tube. The lower part of the tube *E* is made of silver. The mouth of the test tube is closed with tightly fitting cork having two holes through which pass a delicate thermometer *t* and a glass tube *A* down to the bottom of the tube. The side tube of this test tube *E* is connected to a vertical stand of brass, which in turn is connected to the rubber tube joined to an aspirator *D*. A second glass test tube *F* identical to the test tube *E* is also mounted to the same vertical stand having a thermometer *T* in it. The lower portion also is made of silver. Its mouth is closed with a tightly fitting cork through which passes a thermometer *T*. The test tube *F* is meant for comparison purposes only. Some ether is placed in test tube *E* in which one end of a glass tube *A* and bulb of thermometer *t* are dipping. The aspirator contains water and at the lower end of this is a stop cock.



(Fig. 2.39)

Theory. As described in Daniell's hygrometer.

Procedure. (i) Connect the aspirator and the vertical brass stand by the rubber tube *R*. The distance between the aspirator and the vertical stand *S* should be of the order of two to three metres. Place a telescope in the vicinity of aspirator and focus it till the metallic surfaces of both the test tubes are focussed.

(ii) Fill half of the test tube *E* with ether so that the level of ether in the tube is above the height of silver cap and the lower end of tube *A* and bulb of thermometer *t* is well within the ether. Open the tap of the aspirator and regulate the aspirator so that the cooling is slow. Water runs out of it and to fill its place, a steady stream of air enters through the bent tube and bubbles through the ether. It causes a rapid evaporation of ether, this results in cooling of the liquid, the silver cap of the tube and the air surrounding it. With passing away of air moving through the ether, the temp. of the surrounding goes on falling and ultimately a stage is reached when the saturation is achieved and consequently, dew appears on the silver surface of *E*. Observe through the telescope the first appearance of the dew and read the thermometer as soon as the dew appears on the silvered surface of *E*. The first appearance of dew in *E* is detected by using the silver surface of *F* for comparing or contratsing the brightness of the two silver caps. Now read the temperature from the thermometer *T* in test tube *F* to get the temp. of air.

(iii) When the temp. of ether has fallen below the dew point, close the tap of aspirator. As the flow of air is closed, the temperature of the ether, and, therefore, that of the silver cap now begins to rise resulting in the gradual disappearance of the dew from it. Read the temp. from the thermometer *t* when the last trace of dew just disappears from the silvered surface of test tube *E*. The mean of these two temperatures gives the correct value of the dew point.

(iv) Repeat the experiment as described above and take sets of readings and tabulate the results as in the last experiment (Daniell's hygrometer) and hence calculate the relative humidity.

Precautions. (i) Keep the apparatus away from the sink.

(ii) Both the thermometers should be sensitive i.e. reading $\frac{1}{5}$th of a degree at least.

(iii) Regulate the flow of water with aspirator so that flow of air may not be rapid, otherwise it would be difficult to observe the exact dew point.

(iv) The temperature for disappearance of dew is generally found to be higher than the temp. for appearance of dew. Hence, practice should be made to distinguish a dim silver surface due to deposit of water vapour from the bright surface. This would help in reducing the difierence between the two temperatures.

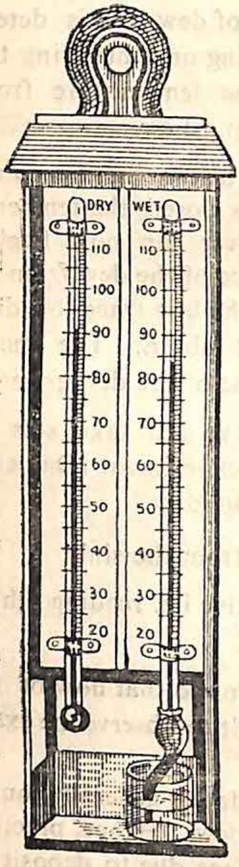
(v) If the telescope is not available and reading is being taken from naked eye, the experiments should be about 40 cm away from the apparatus, otherwise the air in the vicinity of it would be contaminated.

(vi) See the precautions mentioned in the previous expt. also.

EXPERIMENT 20. To determine the relative humidity of air by wet and dry bulb hygrometer.

Apparatus. Wet and dry bulb hygrometer.

Description of the apparatus. WET AND DRY BULB HYGROMETER : This hygrometer consists of two mercury thermometers nearly 10 cm apart and placed vertically side by side on a board. The bulb of one thermometer is exposed to air and gives the temperature of atmospheric air. The bulb of the other thermometer is wrapped round with muslin which is always kept moist by dipping its free end into water contained in a beaker placed on the board. Due to the evaporation the temperature of the wet bulb falls. [The drier the air the greater would be the evaporation from the wet bulb and hence its temp. would be much below the temp. of the dry bulb.]



(Fig. 2.40)

During the evaporation water takes its latent heat from the bulb of the thermometer itself, so the wet bulb thermometer always records a lower temp. than the dry bulb thermometer which records the temp. of air. The difference between the two temperatures indicates the hygrometric state of the air.

Theory. Let T°C be the temperature of dry bulb thermometer and t°C be the temperature of wet bulb thermometer, then the dew point t_1°C will be given by the Glaisher's formula

$$T-t_1=F(T-t) \qquad \ldots (1)$$

where F is Glaisher's constant and its value is found from the table given on the page 234.

From this formula the value of dew point t_1°C is determined. Corresponding to the temperatures t_1°C and T°C the saturated vapour pressures f and F are obtained from Regnault's tables and so the relative humidity is calculated applying the formula—

$$\text{R.H.} = \frac{f}{F} \times 100 \qquad \dots (2).$$

Procedure. (i) Hang up the wet and dry bulb hygrometer against a vertical wall of open verandah which should be free from air draughts. Cover the bulb of one of the thermometer with muslin. Fill some water in the beaker into which the free end of muslin dips. The water will be sucked up and will reach the muslin covering the bulb of the thermometer.

(ii) As the air passes, the water from the surface of the muslin wrapped round the wet bulb thermometer will evaporate, resulting in lowering the temperature of wet bulb thermometer. Note the falling temperature. Take a number of readings at regular intervals of 2 to 3 minutes when the temp. of wet bulb becomes nearly stationary. Take the average of these temperatures from which the temp. (t) of wet bulb thermometer will be obtained.

(iii) Note the temperature (T) from the dry bulb thermometer.

With the help of these two temperatures and the Glaisher's formula, obtain the dew point (t°C). Now consult the Regnault's table and find out the value of saturated vapour pressures corresponding to the temperatures t_1°C and T°C.

(iv) Enter the results in a table and hence calculate the R. H. from the formula (2).

Observations

Day
Date—
Time—

No. of obs.	Temp. in °C			
	Dry bulb	Mean (T)	Wet bulb	Mean (t)

Glaisher's factor F corresponding to dry bulb temperature is obtained from the following table.

Dry bulb temp. in °C	Glaisher's Factor (F)	Dry bulb temp. in °C	Glaisher's factor F
4	7·82	16	1·87
5	7·28	18	1·83
6	6·62	20	1·79
7	5·77	22	1·75
8	4·92	24	1·72
9	4·04	26	1·69
10	2·06	28	1·67
11	2·02	30	1·65
12	1·99	32	1·63
14	1·92	34	1·61
		36	1·59

Calculations.

$$T-t_1=F(T-t).$$

On proper substitution, $t_1=\ldots$ °C.
From Regnault's table—....
Saturated vapour pressure (f) at dew point (t_1°C) = ...mm.
Saturated vapour pressure (F) at atmospheric air temp. (T°C) = ...mm.

$$\therefore \quad \text{R.H.}=\frac{f}{F}\times 100$$

$$=\ldots.\%$$

Result = ...%

Precautions. (i) Apparatus should be placed in such a place where the effects due to draught of air can be avoided.

(ii) Note the temp. of wet bulb when its temp. is stationary. To ensure the steadiness of temp. of wet bulb thermometer, repeat the observation at regular intervals of times.

(iii) The experimenter should be about 40 cm. away from the apparatus.

ASSOCIATED EXPERIMENTS

1. Find the amount of moisture per litre of air in your laboratory.

Hint. Let t be the temperature of air in the laboratory and P be the atmospheric pressure. Let V_2 be the volume at N. T. P. corresponding to 1 litre at room temperature and pressure.

Hence, from the gas law, we have

$$\frac{PV}{T}=\text{constant}$$

$$\text{i.e.} \qquad \frac{P\times 1}{t+273}=\frac{760\times V_2}{273}$$

$$\therefore \quad V_2=\frac{P\times 273}{760\times(t+273)} \text{ litre} \qquad .. \quad (1)$$

Density of air at N.T.P. = ·001293 gm/c.c.

= 1·293 gm/litre.

So, the density of moisture at N.T.P.

$=\frac{5}{8}\times 1{\cdot}293$ gm./litre

Hence, the mass of moisture to saturate one litre of air at $t°\text{C}=V_2\times\frac{5}{8}\times 1{\cdot}293$ gm. .. (2)

But, from the definition of relative humidity P, we have

$$R=\frac{\text{Amount of moisture present in any volume at } t°\text{C}}{\text{Amount of moisture to saturate the same volume of air at } t°\text{C}}$$

$$=\frac{\text{Amount of moisture present in one litre of air at } t°\text{C}}{\text{Amount of moisture to saturate one litre of air at } t°\text{C}}.$$

Hence, amount of moisture present in one litre of air (in the laboratory) at $t°$C

$=R\times$ Amount of moisture to saturate one litre of air at $t°$C

$=R\times V_2\times\frac{5}{8}\times 1{\cdot}293$ gm. .. (3)

Now, from the observed value of P and t, calculate V_2 from the relation (1).

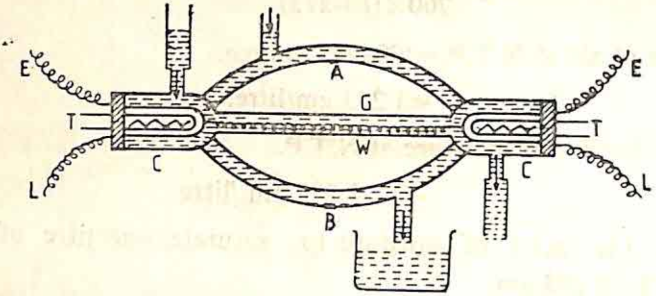
Determine the relative humidity R by any of the methods described above and hence calculate the amount of moisture present in one litre of air in your laboratory using the relation (3).

□□□

MECHANICAL EQUIVALENT OF HEAT

EXPERIMENT 21. Determination of Mechanical Equivalent of Heat (*J*) by Callendar and Barne's Continuous Flow Method.

Apparatus. Callendar and Barne's apparatus, constant water head arrangement, ammeter, voltmeter, stop-watch, beaker, rheostat, two sensitive thermometers, an accumulator of 12-18 volt, watt-box etc.



(Fig. 2.41)

Description of apparatus. A thin platinum wire *W* wound like a spiral is placed co-axially in a glass or quartz tube *G* as shown in figure. Both the ends of tube *G* are connected to two thick copper tubes *C-C* which are connected to both the ends of wire *W*. Copper-tubes *C-C* are connected to two leads *L-L* through which an electric current is allowed to flow. As a result of this flow of current the wire *W* gets heated. When a stream of water is allowed to flow through the tube *G*, the water comes into contact with the wire *W* and the water is heated. As a result of this the temperature of the outflowing water becomes higher than the temperature of the incoming water through the tube *G*. These temperatures are measured with the help of two thermometers *T-T* whose bulbs remain inserted in the copper tubes *C-C*. This can be seen in fig. 2.41. Copper is a good conductor of heat. So it maintains the same temperature as that of adjacent water and the temperatures are noted with the help of the two thermometers *T-T*. As the resistance of copper is very low it produces negligible heat on account of electric current. Two wires

E-E are connected to the two copper-tubes and the other ends of *E-E* are connected to a voltmeter to measure the potential difference between the two ends of *W*. Tube *G* is covered with a vacuum jacket *A*. In order to avoid the loss of heat due to radiation, tube *G* is covered with a vacuum jacket *A* which itself remains covered with a jacket *B* of water.

Theory. When the electric current through *W* and stream of water through *G* is allowed to flow, the temperature of outflowing water begins to rise. After some time the temperature of water becomes steady. In the steady state, the amount of water *M* outflowed through tube *G* in time *t* is measured along with the electric current *I* and the potential difference *E* between the two ends of wire *W*.

Let θ_1°C and θ_2°C be the temperatures of inflowing and outflowing water in tube *G*. Hence the amount of heat generated in the wire is

$$\frac{EIt\times 10^7}{J}=m(\theta_2-\theta_1)+\triangle Q \quad .. \quad \text{(i)}$$

where *J* is the mechanical equivalent of heat in ergs/calorie.

$\triangle Q$ is the loss of heat due to radiation. If the strength of current *I* is changed to *I′* the potential difference between the two ends of *W* changes from *E* to *E′*. Now the flow of water through tube *G* is so adjusted that the difference of temperature between the inflowing and outflowing water remains $(\theta_2-\theta_1)$. Let m_1 be the mass of water outflowed through the tube in time *t* in the steady state. Hence the amount of heat generated is

$$\frac{E_1I_1t\times 10^7}{J}=m_1(\theta_2-\theta_1)+\triangle Q \quad .. \quad \text{(ii)}$$

So from eq. (i) and (ii),

$$\frac{(E_1I_1-EI)t\times 10^7}{J}=(m_1-m)(\theta_2-\theta_1)$$

$$\therefore \quad J=\frac{(E_1I_1-ET)t\times 10^7}{(m_1-m)(\theta_2-\theta_1)} \text{ erg/cal.} \quad .. \quad \text{(iii)}$$

Procedure. (i) Arrange the apparatus as shown in the fig. 2.41. Regulate the supply of water through the tube in such a way that the flow of water per minute may be nearly 50-60 c.c. This can be achieved with the help of constant pressure water head. Insert the bulbs of thermometers *T-T* at the two ends of the tube *G* (one where the water enters and the other where the water leaves out). Connect a key, a rheostat, and an accumulator with the leads *L-L* in series. At the same time connect a voltmeter and a key between *E-E*. Clean, dry and weigh a beaker.

(ii) Allow the stream of water to flow through *G*. Afterwards allow the electric current to flow through the wire *W*. Remove the air bubble (if there is) due to rise of temperature. Regulate the rate of flow of water such that flow of outflowing water may be low. Adjust the strength of current in such a way that difference of temperatures between the inflowing and outflowing water may not exceed 5-10°C. In the steady state note down the temperature of inflowing and outflowing water in the tube *G*. Let it be θ_1°C and θ_2°C. Measure the electric current and potential difference with the help of ammeter and voltmeter. Let I and E be the strength of current and the potential difference respectively. Now place a weighed beaker below the outflowing water and instantaneously start the stop-watch to note time. Remove the beaker after t seconds. Weigh the beaker again. Now calculate the mass m of collected water in the beaker.

(iii) Change the strength of current I to I_1 with the help of rheostat so that the value of E changes to E_1. Repeat the experiment for the same time t maintaining the same difference of temperature $(\theta_2 - \theta_1)$°C. Let m_1 be the mass of water collected in the beaker this time. Repeat the experiment several times by changing the value of I and E and then calculate the mean value of J i.e. the mechanical equivalent of heat.

Observations and Calculations

No. of Observation	Mass of empty beaker in gm	Mass of (beaker+water) in gm	Time=t sec	Mass of water in 120 sec=m	Reading of Ammeter in ampere=I	Reading of voltmeter in volts =E	$E \times I$	Temp. of water entering the tube=θ_1°C	Temperature of outflowing water=θ_2°C	Difference of temp. in °C	Value of J in ergs/cal.	Mean value of J
1.	89·815	151·175	120	61·360	1·92	7·35	14·112	23·6	28·6	5	4·14 × 10^7	4·23 × 10^7 ergs/cal
2.	89·815	157·421	120	67·606	2·0	7·5	15·0	23·6	28·6	5	4·32 × 10^7	
3.	89·815	170·239	120	80·424	2·18	8·05	17·540	23·6	28·6	5		

Experimental value of $J = 4{\cdot}23 \times 10^7$ erg/cal.

Standard value of $J = 4{\cdot}20 \times 10^7$ erg/cal.

∴ % error=0·714%.

Precautions : (i) The thermometers should be sensitive reading up to $\frac{1}{8}$ of °C.

(ii) Measurement of time with stop-watch and placing of beaker below the outflowing water in the steady state should be simultaneous.

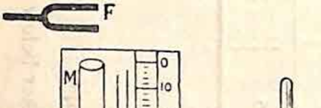
3. SOUND

WAVELENGTH OF SOUND

EXPERIMENT 1. Determination of the Velocity of Sound in CO_2 gas by Resonance Column Apparatus.

Apparatus. Resonance columan apparatus, tuning fork, jars containing CO_2 gas.

Description of the apparatus. RESONANCE COLUMN APPARATUS : The apparatus consists of a long hollow tube *MN* of either glass or brass fitted on a vertical wooden board standing on a horizontal wooden board supported by three levelling screws—one at the back and two in the front. The upper end of the tube *MN* is open while the lower end ends into a nozzle to which is connected a long rubber tube *T*. The other end of the rubber tube is connected to a reservoir *R* supported by means of clamp. By raising or lowering the reservoir, the water level in the tube *MN*, may be fixed at any desired height. In between the tube *MN* and the reservoir, there is provided a metre scale *S* fixed on the same vertical wooden board to mark the water level in the tube.



(Fig. 3.1)

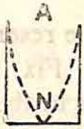
In certain apparatuses, particularly where the tube *MN* is not of glass, a side tube *P* of glass is provided from which the position of water level in the tube may be easily read out.

Theory. The principle, on which the above experiment is based, is the same as that employed for the determination of velocity of sound in air by resonance column—the only difference here is to replace air, in the tube *MN* over water surface, by CO_2 gas.

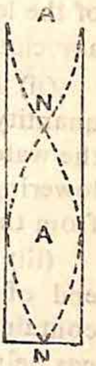
If a vibrating tuning fork is held near and above the free end of the tube *MN*, it sets up columns of compressions and rarefactions in the adjoining medium, which is here carbon dioxide gas, and these travel with a definite velocity. The sound waves, moving in the column of CO_2 contained in the tube, impinge on the surface of water and get reflected. These direct and the reflected waves of sound are superimposed resulting in the formation of what is called stationary wave.

When the length of the vibrating column of CO_2 gas is adjusted, by gradually raising or lowering the water surface in the tube, a position will be found when the intensity of sound heard is maximum. This is the position of first resonance as indicated in the adjoining fig. 3.2 (a) where there is an antinode A at the open end and node N at the closed end such that the length of the column of CO_2 in the tube is given by $l_1=\lambda/4$ .. (1) where λ is the wave-length of sound waves.

On futher lowering the water level in the tube there is again obtained a position when the intensity of sound heard is maximum. This is the position of second resonance as indicated in fig. 3.2 (b) where there are two antinodes A, A and two nodes N, N and the length of the vibrating column is given by



[Fig. 3.2 (a)]



[Fig. 3.2 (b)]

$$l_2=\frac{3\lambda}{4} \quad .. \quad (2).$$

Combining the two equations, we have

$$l_2-l_1=\lambda/2$$

i.e. $$\lambda=2(l_2-l_1) \quad .. \quad (3).$$

If n be the frequency of tuning fork, the velocity V of sound (in CO_2) is obtained by the relation

$$V=n\lambda=2n(l_2-l_1) \quad .. \quad (4).$$

Thus, from the determination of l_1 and l_2, the velocity of sound in the desired medium can be found out.

In actual practice however, the antinode is formed not just at the open end but at a small distance above it. This distance is found to be a function of the internal radius r of the tube, and is called the end-correction. According to Rayleigh, this end-correction x is 0·6 times the internal radius of the tube. Hence, taking this correction also in account, we have,

for the first resonance $l_1+x=\lambda/4$ .. (5)

and for the second resonance $l_2+x=3\lambda/4$ .. (6).

Hence $$x=\frac{l_2-3l_1}{2} \quad .. \quad (7)$$

and also $\lambda=2(l_2-l_1)$.

Therefore $V=n\lambda=2n(l_2-l_1)$ which is identical with the expression (4).

Procedure. (i) Set up the apparatus as shown above. By means of the levelling screws provided at the base, make the tube *MN* and associated parts vertical.

(ii) Pour some water in the tube through the reservoir *R*. The quantity of water taken should be such that on raising the reservoir, the water level should be close to the free end of the tube and on lowering it up to the lowest position, the water may not overflow from the tube.

(iii) Raising the reservoir, bring the water surface near the open end of the tube. Fix the reservoir by clamp. Now invert a jar, containing CO_2 gas at the mouth of the tube *MN*. Carbon dioxide gas being heavier than air will expel out the air in the tube, above the water surface and the tube will be filled with CO_2 gas. Test by a burning match-stick, which will be extinguished in CO_2 gas, whether the tube is completely filled with CO_2 gas.

(iv) Take a tuning fork of known frequency. Strike it against a rubber pad and hold it a little above the tube *MN*. Starting with a small length of the tube above the surface of water, go on increasing it until the sound heard is intense. Now adjust the water level in the tube more carefully till the intensity of sound is maximum—when resonance is said to occur. First, test whether the tube is filled with CO_2 gas and then mark the position of resonance twice—once while raising and then while lowering the reservoir. The mean of the two values of the above readings will give l_1 which will be nearly equal to one-fourth of the wave-length λ.

(v) Lowering the reservoir, increase the length of the tube, above water level, up to nearly three times the value of l_1 determined in the operation (iv).

Fill the tube again with CO_2 gas, as directed in the operation (iii) and adjusting the reservoir more carefully, obtain the second resonance. Measure the length of the tube, above water surface corresponding to the second resonance. Take two readings here also—one while raising and the other while lowering the reservoir, The mean of these two readings will give the value of l_2 which will be nearly equal to $3\lambda/4$.

(vi) Note the frequency of the tuning fork and using the formula given above, calculate the velocity of sound in CO_2 gas.

(vii) Repeat the above operations with at least two more tuning forks. Calculate the average value of the velocity of sound in CO_2 gas.

(viii) Note the temp. of the column of CO_2 in the tube and reduce the velocity of sound in CO_2 gas to that at 0°C employing the relation

$$V_0 = V_t\left(1 - \frac{t}{546}\right).$$

(ix) Enter the results in the table given below.

Observations and Calculations

No. of obs.	Freq. of the tuning fork	Length of the tube corresponding to the 1st resonance $=l_1$ cm			Length of the tube corresponding to the 2nd resonance $=l_2$ cm			$\lambda=2(l_2-l_1)$ cm	$V=n\lambda$ $=2n(l_2-l_1)$ cm/sec	Average V (cm/sec)
		I	II	Mean	I	II	Mean			
1										
2										
3										

Results. Velocity of sound in CO_2 gas at t°C, $V = \ldots\ldots$ cm/sec.

Velocity of sound in CO_2 gas at 0°C, $V_0 = \ldots\ldots$ cm/sec.

Precautions. (i) The experiment should be performed at a place where there is practically no noise. (ii) Strike the tuning fork against the rubber pad gently so that any metallic sound may not be produced. (iii) The vibrating tuning fork should be held a few centimetres above the mouth of the tube and must not touch the wall of the tube. (iv) If the point of resonance is found to be not sharp, the readings should be taken by holding the fork at some distance from the mouth of the tube so that the range of maximum intensity may be reduced to a minimum.

ASSOCIATED EXPERIMENTS

1. To determine the frequency of a given tuning fork. The velocity of sound in air at room temp. is given.

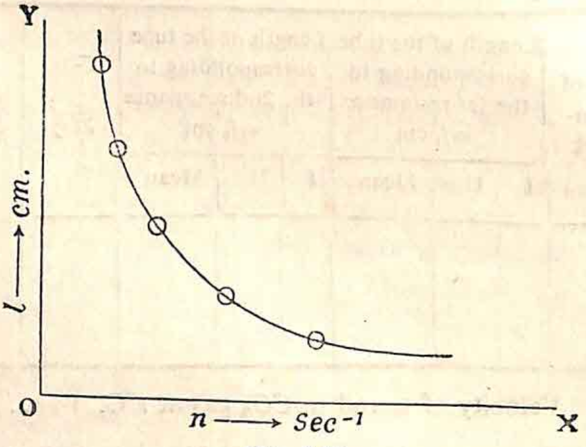
Hints. Repeat the above experiment with the given tuning fork. Taking air in the tube, above water surface, determine the positions of first and second resonance and hence calculate (l_2-l_1). Since V is given, calculate the unknown frequency of the tuning fork, from the relation

$$V=n\lambda=2n(l_2-l_1)$$

i.e. $$n=\frac{V}{2(l_2-l_1)}.$$

2. To show how the length of the resonance column depends upon the frequency of the tuning fork.

Hints. Repeat the above experiment with at least five tuning forks of known frequency. Determine the length of the tube l (above the water surface) corresponding to the first resonance for each tuning fork. Finally, plot a graph with frequency n on x-axis and the length l on y-axis. The curve will be a rectangular hyperbola, as shown above, which will show the dependence of resonant length on frequency.



(Fig. 3.3)

3. To find acoustically the end-correction of the given resonance tube.

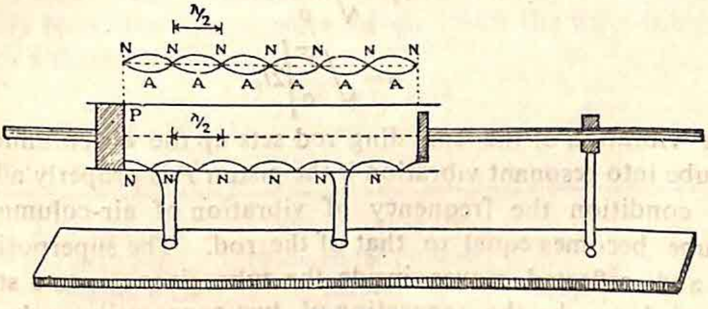
Hints. Repeat the above experiment with a tuning fork of known frequency and determine the lengths of resonance tube (above the surface of water) corresponding to the first and second resonances.

Call them as l_1 and l_2. Now, employing the relation (7), in the theory of the above experiment, find the end-correction x. Repeat the above operation with two more tuning fork and calculate x in each case. The average of these will give the mean end-correction.

EXPERIMENT 2. To determine the velocity of sound in air by Kundt's tube.

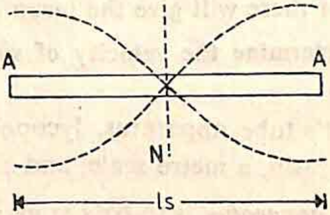
Apparatus. Kundt's tube apparatus, lycopodium powder, a piece of leather, powdered resin, a metre scale, and a thermometer.

Description of the apparatus. KUNDT'S TUBE : It consists of a glass tube about one metre long, having a diameter of 5 cm. An adjustable piston P is used to close one end of the tube. The tube is called the 'Wave-tube'. A rod of about one metre provided with a disc of diameter slightly smaller than the diameter of the wave-tube at one end is clamped exactly at its mid point, and its end with the disc is placed inside the wave-tube. This rod is called the 'sounding rod'. The sounding rod is arranged to be along the axis of the wave-tube. When the free half of the sounding rod is pulled with the leather piece dusted with resin powder along its length, it executes longitudinal vibrations. The procedure of making the rod vibrate is called 'stroking'. The vibration of the rod causes forced vibration of the air-column inside the wave-tube. This piston P can be adjusted along the wave-tube suitably to set the air-column of the wave-tube into resonant vibration when the sounding tube is stroked. If the wave tube is dusted with dry lycopodium powder, then, because of the formation of standing waves inside the wave tube, the lycopodium powder collects in heaps on the nodes. The distance between the centres of two consecutive heaps of lycopodium powder is equal to half the wave-length of sound in air.



(Fig. 3.4)

Theory. A rod of length l_s cm when clamped at its mid point vibrates longitudinally having a node at its mid point and antinodes at its free ends. The wave-length λ_s of the vibration in the rod is, therefore, $\lambda_s = 2l_s$. If n be the frequency of vibration of the rod, the



(Fig. 3.5)

velocity v_s of sound in the rod will be given by

$$v_s = 2l_s n$$

so that, $$n = \frac{v_s}{2l_s}.$$

If Y be the Young's modulus, and ρ be the density of the material of the rod, then

$$v_s = \sqrt{\frac{Y}{\rho}}$$

$$\therefore \qquad n = \sqrt{\frac{Y}{\rho}} \Big/ 2l_s \qquad .. \quad (1).$$

The vibration of the sounding rod sets up the air-column of the wave-tube into resonant vibration if the piston P is properly adjusted. In this condition the frequency of vibration of air-column in the wave-tube becomes equal to that of the rod. The superposition of direct and reflected waves inside the tube gives rise to a standing wave. If l_a cm be the separation of two consecutive nodes of the standing wave and v_a be the velocity of sound in air, then,

$v_a = n\lambda_a = n.2l_a$, where λ_a = wave-length of sound in air

so that $$n = \frac{v_a}{2l_a} \qquad .. \quad (2).$$

Combining equations (1) and (2), we have

$$\frac{v_a}{2l_a} = \sqrt{\frac{Y}{\rho}} \Big/ 2l_s$$

$$v_a = \frac{l_a}{l_s} . \sqrt{\frac{Y}{\rho}}.$$

Procedure. (i) Make the inner surface of the glass tube of the apparatus dry by blowing a stream of hot air through it.

(ii) Obtain some dry lycopodium powder by putting the powder on a piece of paper in the sun for about half an hour. Tilt the glass tube and put a small quantity of powder in it. Gently tap the tube to obtain a 2 mm wide line of lycopodium powder along the length of the tube.

(iii) Arrange the tube on the stand of the apparatus. Check if the sounding rod is clamped exactly at its mid point. Dust the piece of leather with resin powder and pull along length of the rod with leather. The rod will sound freely if it is clamped at its mid point.

(iv) Now adjust the piston *P* at the other end of the tube gradually by pushing it inside the tube by about 1 cm and keep on stroking the sounding rod until it is found that lycopodium powder particles put inside the wave-tube vibrate vigorously, and they collect prominently at the nodes. It will be necessary to move the piston *P* very slowly for the final adjustment for resonance.

(v) Measure the distance between the centres of the clear extreme heaps (nodes) of the powder. Let this be *d* cm. Count the number *p* of antinodes between these heaps. The value of l_a will be d/p cm.

(vi) Repeat the determination of l_a at least thrice.

(vii) Note the temperature of air inside the wave-tube with the help of a thermometer.

Observations

Temperature = 30·0°C.

Length of the rod = l_s = 123·0 cm

No. of obs.	Distance between clear extreme heaps = *d* cm	No. of antinodes between the extreme heaps = *p*	$l_a = \frac{d}{p}$ in cm	Mean l_a in cm
1	37·80	3	12·60	
2	50·48	4	12·62	12·61
3	63·05	5	12·61	

Calculations.

Material of the rod = Brass.

Value of *Y* of the material of the rod = $9{\cdot}7\times10^{11}$ dyne/sq. cm.

" " ρ " " " = 8·4 gm/c.c.

$$\therefore \quad v_a=\frac{l_a}{l_s}\sqrt{\frac{Y}{\rho}}=\frac{12\cdot61}{123}\sqrt{\frac{9\cdot7\times10^{11}}{8\cdot4}}=3484\cdot2 \text{ cm/sec}$$

$$=348\cdot42 \text{ metres/sec.}$$

Temperature Correction.

If v_{at} be the velocity of sound in air at t°C and v_{a0} be the velocity of sound in air at 0°C, then

$$v_{a0}-v_{at}\,(1-\tfrac{1}{2}\alpha t)=348\cdot42\,(1-\tfrac{1}{2}\times0\cdot00367\times30)$$

$$=329\cdot23 \text{ m/sec}$$

where α = coefficient of expansion of air

$=0\ 00367$

$\therefore$ %error = 0·60%.

Hence if v_{at} is determined, the value of velocity of sound in air at 0°C can be calculated from the above expression.

Humidity Correction.

If f mm of mercury be the pressure of the aqueous vapour at t°C, and P is the pressure of air in mm of mercury at t°C, then, the velocity of sound in dry air v_{atd} is given by

$$v_{atd}=v_{at}\sqrt{\frac{P-0\cdot38f}{P}}$$

$\therefore$ Velocity v_0 of sound in dry air at 0°C is given by

$$v_0=v_{at}\sqrt{\frac{P-0\cdot38f}{P}}\times(1-\tfrac{1}{2}\,\alpha t).$$

Note. Instead of making use of the values of Y and ρ of the material of the rod taken from a book of physical constants, the frequency n of the rod may be determined with a sonometer, and the value of the velocity of sound in air may then be determined by the relation,

$$v_a=n.2l_a.$$

The following steps may be followed to determine the frequency of the rod by a sonometer :

(i) Take a tuning fork of known frequency and adjust the distance between the bridges of the sonometer placed below the wire to hear the waxing and waning of the sound (beats) when both the tuning fork and sonometer are sounded together. Make further adjustments of the distance between the bridges gradually so that the number of beats heard per second gradually diminish and finally disappear. Now measure the length l' of the wire between the bridges. The frequency

n' of the tuning fork will be

$n'=\frac{1}{2l'}\sqrt{\frac{T}{m}}$, where T = tension applied to the sonometer wire,

and m = mass per unit length of the wire.

(ii) Now, stroke the sounding rod of the Kundt's tube, and sound the sonometer. Adjust the distance between the bridges of the sonometer to hear beats when both the sounding rod and the sonometer are sounded together. Keep on adjusting the distance between the bridges so that the number of beats heard per second gradually diminish and finally disappear. Now measure the length l of the wire between the bridges. The frequency n of the rod will be

$$n=\frac{1}{2l}\sqrt{\frac{T}{m}}.$$

Hence, $\frac{n}{n'}=\frac{l'}{l}$, or $n-n'.\frac{l'}{l}$, so that if n' is known, n may be calculated.

ASSOCIATED EXPERIMENTS

1. To determine the velocity of sound in carbon dioxide gas.

Hints. Take a Kundt's tube apparatus with an inlet hole in a cork arranged behind the piston P. Prepare the carbon dioxide gas in a Kipp's apparatus and pass it through drying tubes. Then pass the gas into the wave-tube through the inlet until the air inside the tube is fully replaced by the gas. There should be another cork with an outlet hole arranged behind the piston of the sounding rod for the exit of the gas. Now determine the length l_g between the centres of the consecutive heaps of the lycopodium powder following the procedure described in the Expt. No. 2. If the frequency n of the sounding rod has been determined by sonometer, then the velocity v_g of sound in carbon dioxide is given by

$$v_g=n\times 2l_g.$$

2. To compare the velocity of sound in two gases.

Hints. Let l_{g_1}, and l_{g_2} be the distances between the centres of consecutive heaps in the two gases respectively. Then the ratio of the velocities v_{g1} and v_{g_2} of sound in the two gases will be given by

$$\frac{v_{g_1}}{v_{g_2}}=\frac{n.2l_{g_1}}{n.2l_{g_2}}=\frac{l_{g_1}}{l_{g_2}}.$$

3. To determine the velocity of sound in the material of the sounding rod.

Hints. The velocity of sound v_s in the material of the rod is given by $v_s = n \times 2l_s$, where l_s is the length of the rod and the velocity of sound v_a in air is given by

$v_a = n \times 2l_a$, where l_a = distance between two consecutive nodes.

$$\therefore \quad \frac{v_s}{v_a} = \frac{n \times 2l_s}{n \times 2l_a} = \frac{l_s}{l_a}$$

or $v_s = v_a \times \frac{l_s}{l_a}$. Hence, if the value of velocity of sound in air is assumed, then the velocity of sound in the material of the rod can be calculated.

4. To determine the ratio of two specific heats of gas, γ, by Kundt's tube experiment.

Hints. The velocity of sound, v_0, in air at 0°C is given by

$v_0 = \sqrt{\frac{P\gamma}{D}}$, where P = normal pressure of air in absolute unit

$= 76 \times 13{\cdot}6 \times 981$ dynes/sq cm,

D = density of dry air at N. T. P. = $0{\cdot}001293$ gm/c.c.

and γ = ratio of the two specific heats of air.

Hence if the value of v_0 is determined as explained in Expt. No. 2, then the value of γ can be calculated from the relation

$$\gamma = \frac{v_0^2 D}{P}.$$

5. To determine the Young's modulus of the material of the sounding rod.

Hints. The velocity of sound, v_s, in the material of the sounding rod is given by $v_s = \sqrt{\frac{Y}{D}}$, where Y and D are the Young's modulus and density respectively of the material of the rod.

The value of v_s can be determined by the method described in the associated Expt. No. 3, and the density of the material of the rod also can be easily determined. Hence Y can be calculated from the above relation.

VIBRATION OF STRINGS AND FREQUENCY DETERMINATION

EXPERIMENT 3. Determination of the frequency of a tuning fork by Melde's Experiment.

Apparatus. Tuning fork, string, pulley, pan, table, clamp, balance, weight-box, bow, two pin-stands, scale.

Description of the apparatus. The practical arrangement of the apparatus for this experiment consists of a rigidly mounted tuning fork and a pulley. One end of a uniform string is attached to one prong of the tuning fork while the other end, passing over the pulley, carries a pan on which weights can be placed so as to keep the string stretched and in tension. The positions of the nodes on the vibrating string are marked by pin points carried on two movable stands.

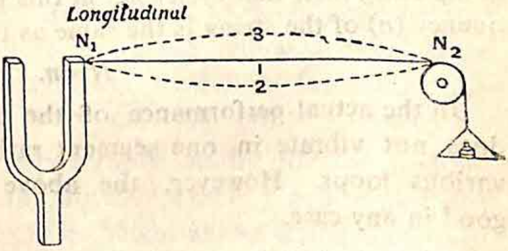
Theory. The string is fixed horizontally while the tuning fork may be placed either in the longitudinal or in the transverse position.

LONGITUDINAL POSITIONS OF THE TUNING FORK

When the vibrations of the prongs of the tuning fork are along the length of the string, it is said to be in the longitudinal position (Fig. 3.6).

Since the two ends of the string are fixed and are not free to vibrate, so on setting the string in vibration, they will always be the points of nodes.

In this position, in course of vibration, when the prong, to which the string is attached, reaches the extreme outward position (i.e. extreme right in the fig.), the string, being slackest, sags and comes to rest (as shown by the lower dotted line). The prong continues to vibrate and after half a period when it reaches the extreme inward position (i.e. extreme left in the fig.), the string becomes most tightened and moving upward, occupies the horizontal position (as shown by the full line). Again, after next half period, when the prong reaches the extreme outward position, the string becomes slackest, but owing to inertia of upward motion, the string goes up and occupies the position shown by the upper dotted line, instead of sagging.



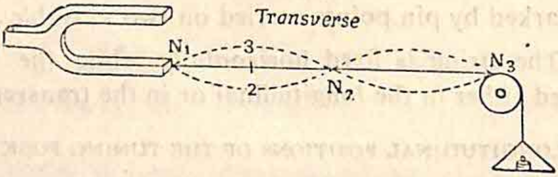
(Fig. 3.6)

Thus by the time the fork completes one oscillation, the string completes only half oscillation i.e. the time period of oscillation of string is double that of the fork i.e. the frequency (n) of the string is half that of the fork (N).

Hence, in the longitudinal position of fork, frequency (n) of the string $= \frac{1}{2}$ frequency of the fork (N) i.e., $N = 2n$.

TRANSVERSE POSITION OF THE TUNING FORK

When the prongs vibrate perpendicularly to the length of the string, the fork is said to be in the transverse position (Fig. 3.7).



(Fig. 3.7)

In this position of the tuning fork, it is readily seen that the string is most tightened both when the prong, to which the string is attached, is in the extreme outward or extreme inward position. In other words, both the string and the fork take the same time interval in completing their half cycles i.e. in this position of the fork, the frequency (n) of the string is the same as that of the fork i.e.

$$N = n.$$

In the actual performance of the experiment the whole string does not vibrate in one segment rather it usually breaks up into various loops. However, the above relations continue to hold good in any case.

When the fork is excited, transverse vibrations are set up in the string and the frequency of the vibrating string is given by

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}},$$

where l = distance between any two consecutive nodes,
T = tension applied to the string,
m = mass of unit length of the string.

Thus, from the experiment, l, T and m being known, the frequency (n) of the vibrating string can be found out and hence the frequency of the tuning fork

$$N = 2n \text{ (for longitudinal position),}$$

and

$$N = n \text{ (for transverse position).}$$

Procedure. (i) Place the sound box on the working table and clamp it to the longer side, at the edge of the table. Now, rigidly fix the tuning fork to the sound box in either position (i.e. Longitudinal or Transverse) as desired by the experiment (see Fig. 3.6 or 3.7 above).

(ii) Take a string of uniform thickness and of about 1·5 metre length. Tie its one end to one prong of the tuning fork near its tip. To the other end of the string attach a weighed pan and let the string pass over a light pulley fixed at the end of the table so that the pan hangs vertically. Adjust the position of the pulley such that the string, between the fork and pulley, is horizontal and parallel to the edge of the table.

(iii) Place some weight, say 10 or 15 gm on the scale pan and begin your experiment with about one metre length of the string between the pulley and the tuning fork. The total weight suspended from the string, i.e. the weight of the pan plus the weights on the pan will give the tension of the string.

(iv) Excite the tuning fork by drawing a resined bow sharply at one of the edges of the prongs. In general, the amplitude of vibration will be small and will tend to die down quickly. So, adjust the length of the thread, by changing the position of the tuning fork (by about half a cm each time) until, the thread vibrates with large amplitudes. Finally adjust the length more carefully for getting the best position when the vibrating loops will come out very clearly.

(v) Now, set up two pin pointers (horizontally for longitudinal position of the fork and vertically for the transverse position of the fork) by means of clamps at the same height as the string and carefully mark out the positions of two extreme well defined nodes. Measure accurately the distance between the pointers with the help of a metre scale and counting the number of loops in between, calculate the average distance l between two consecutive nodes. Take three sets of such readings.

(vi) Repeat the above operation for different weights on the pan and obtain l for each weight.

(vii) Measure the length of the vertical portion of the string which carries the scale pan including the knot that fastens the scale pan.

(viii) Weigh the scale pan correctly up to a centigram. Also weigh a known length of the string and hence find the mass of unit length of the string.

(ix) Enter your results in the tabular form and calculate n and hence the frequency N of the tuning fork.

Observations and Calculations

No. of observations	Distance between pointers (cm)	No. of loops between pointers	l (cm)	Mean value of l (cm)
1	...	...	...	...
2				
3				

Length of the string taken for weighing = ... cm.
Mass of the string taken for weighing = ... gm.
∴ Mass per unit length of the string (m) = ... gm/cm.
Mass of the scale pan (A) = ... gm.
Weight on the scale pan (B) = ... gm.
Length of the vertical portion of the string carrying the scale pan (L) = ... cm.
∴ Total tension $T = (A+B+Lm)\,g$ = ... dynes.

∴ $n = \frac{1}{2l}\sqrt{\frac{T}{m}}$ = ... per sec.

∴ $N = 2n$ = ...per sec. (for Longitudinal position)
or $= n$ = ...per sec. (for Transverse position).

TABLE 2

Longitudinal position of the Tuning Fork.

Length of string taken for weighing = 103·2 cm.
Mass of string taken for weighing = 0·645 gm.
Mass per unit length of string (m) = $6{\cdot}25 \times 10^{-3}$ gm/cm.
Mass of scale pan (A) = 30·505 gm.
Length of vertical portion of string (L) = 20·0 cm.
∴ $L \times m = 20{\cdot}0 \times 6{\cdot}25 \times 10^{-3} = 0{\cdot}125$ gm.

No. of obs.	Weight on pan (B) (gm)	Total tension $T=(A+B+Lm)\,g$ dyne	Distance between pointers in (cm)	No. of loops between pointers	l cm	Mean of l in cm	Frequency of string $n=\frac{1}{2l}\sqrt{\frac{T}{m}}$	Frequency of tuning fork $N=2n$	Mean of N
1	5	$3{\cdot}492 \times 10^4$	37·10 55·56 73·76	2 3 4	18·55 18·52 18·44	18·50	63·88	127·76	127·35
2	10	$3{\cdot}982 \times 10^4$	39·64 59·70 79·32	2 3 4	19·82 19·90 19·83	19·85	63·58	127·16	
3	15	$4{\cdot}472 \times 10^4$	42·10 63·03 84·32	2 3 4	21·05 21·01 21·08	21·05	63·56	127·12	

TABLE 2

Transverse position of Tuning Fork.

Length of string taken for weighing = 103·2 cm.
Mass of string taken for weighing = 0·645 gm.
Mass per unit length of string $(m) = 6{\cdot}25$ gm/cm.
Mass of scale pan $(A) = 30{\cdot}505$ gm.
Length of vertical portion of string $(L) = 16{\cdot}2$ cm.
$\therefore\ L \times m = 16{\cdot}2 \times 6\ 25 \times 10^{-3} = 0{\cdot}101$ gm.

No. of obs.	Weight of pan (B) in gm	Total tension $T=(A+B+Lm)\,g$ in dyne	Distance between pointers in cm	No. of loops between pointers	l cm	Mean of l in cm	Frequency of string $n=\frac{2}{2l}\sqrt{\frac{T}{m}}$	Frequency of tuning fork $N=n$	Mean of N
1	5	$3{\cdot}489 \times 10^4$	37·20 46·40 56·10	4 5 6	9·30 9·28 9·35	9·31	126·89	126·89	127·25
2	10	$3{\cdot}979 \times 10^4$	39·64 49·80 59·52	4 5 6	9·91 9·96 9·92	9·93	127·24	127·24	
3	15	$4{\cdot}469 \times 10^4$	41·80 52·00 63·00	4 5 6	10·45 10·40 10·50	10·45	127·63	127·63	

Result. Frequency of given tuning fork = 127·25 per sec.

Precautions. (i) Use as uniform string as possible.

(ii) In measuring l, do not measure the distance between the ends of the string at the fork and the pulley, since these points are not perfectly at rest.

ASSOCIATED EXPERIMENTS

1. To prove that the frequency of the string for longitudinal position of the fork is half that of the transverse position.

Hints. Repeat the above experiment first setting the tuning fork in the longitudinal position and then in the transverse position and hence prove the result.

2. To find the linear density of the thread supplied by Melde's method.

Hints. Repeat the above experiment. Use the supplied thread as the experimental string. Taking a tuning fork of known frequency, hold it in either position and determine the length l of the thread between two consecutive nodes for any known tension T. Then using the formula :

$$n=\frac{1}{2l}\sqrt{\frac{T}{m}},$$

find out m which will give the mass per unit length or the linear density of the thread.

3. To compare the frequencies of the two given tuning forks and to verify the result by another method.

Hints. With the given tension and string perform the above experiment and determine the length l_1 for the tuning fork of frequency n_1. Now, without changing the tension and the string, repeat the same experiment with the second tuning fork of frequency n_2 and determine the length l_2 of the string between two consecutive nodes.

Now, $$n_1=\frac{1}{2l_1}\sqrt{\frac{T}{m}} \text{ and } n_2=\frac{1}{2l_2}\sqrt{\frac{T}{m}}.$$

Hence, $\frac{n_1}{n_2}=\frac{l_2}{l_1}$ from which compare the frequencies of the two tuning forks.

Verify this result either by sonometer or by resonance tube method.

4. To determine the weight of the given load by an acoustical method.

Hints. Weighing the thread and measuring the whole length, calculate the mass per unit length of the string. Now, perform the above experiment with a tuning fork of known frequency, with the given load on the pan and determine the length l between the consecutive nodes. From the formula

$$n=\frac{1}{2l}\sqrt{\frac{T}{m}},$$

determine the total tension T.

But total tension $T=$ weight of the pan $(A)+$ weight on the pan $(B)+$ weight of the vertical portion (L) of the thread carrying the pan.

i.e. $T=(A+B+Lm)\,g$ dynes.

Thus knowing A (by weighing) and Lm (by measuring the vertical portion of the thread and multiplying it by m), find out Bg i.e. the weight of the load supplied.

5. **To find the mass of the pan attached to the Melde's apparatus without detaching it. The value of frequency of the fork and a sample of thread is provided.**

Hints. From the given sample of the thread, calculate m, the mass per unit length. Now, place some known mass (say M_1 gm) on the pan. Holding the given tuning fork, whose frequency is known, in any position, find out the value of l. Now, measure the length L of the vertical portion of the thread. Now, using the formula

$$n=\frac{1}{2l}\sqrt{\frac{T}{m}},$$

calculate T, the total tension.

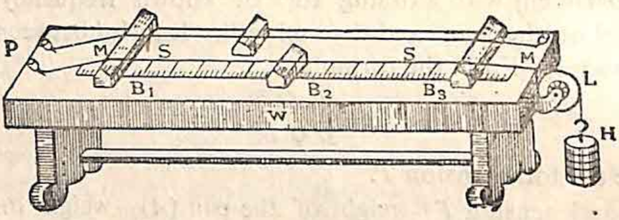
But, the total tension $T=$ (Mass of the pan $+$ mass on the pan $+Lm)\,g$.

Other quantities being known, find out the mass of the pan from the above relation.

EXPERIMENT 4. Verification of the Laws of Transverse vibration of a stretched string by a sonometer.

Apparatus. Sonometer, tuning fork, rough balance and sensitive balance, weight-box, scale etc.

Description of the apparatus. SONOMETER : The sonometer which is a monochord, consists of a hollow wooden box, about a metre long having holes in the sides so that air inside the box can communicate with the air outside, and supported on legs. A wire, called the experimental wire, is tied to a peg P fixed on the board while the other end passes over a pulley and carries a hanger H on which weights can be placed so as to keep the wire stretched and in tension. In



(Fig. 3.8)

between the peg and the pulley, the wire passes over two fixed bridges B_1 and B_2 at the two ends of the box. Another wire called the comparison wire is fixed, parallel to the experimental wire, between another two pegs on the two ends of the box. The apparatus is provided with two or more movable bridges, like B_2, below the wire, to adjust the length of the vibrating wire. The wire is set into vibration either by plucking or by bowing. The frequency of the emitted note can be altered by changing either the distance between the bridges or the tension applied to the wire. There is a metre scale *MM* by the side of the wire, to measure the length of the vibrating wire. The forced vibrations produced in the box, by the vibration of the wire, sets a large volume of air into vibration. Thus even the feeble sound of the wire is intensified and is quite loud for the purpose.

Theory. When a flexible stretched string of length l is plucked and is set into vibration, the transverse waves proceed along the string with a velocity V given by

$$V=\sqrt{\frac{T}{m}} \qquad .. \quad (1)$$

where T is the tension applied to the string (or wire) of mass m per unit length.

If the string vibrates in its fundamental, it will vibrate in one segment having nodes at the two fixed ends and an antinode at the middle so that $l=\lambda/2$ or $\lambda=2l$.

Hence, $$V=n\lambda=n.2l=\sqrt{T/m}.$$

$$\therefore \quad n=\frac{1}{2l}\sqrt{\frac{T}{m}} \qquad .. \quad (2)$$

for the fundamental vibration of the string.

From the above equation (2 , follow the laws of transverse vibration of a stretched string.

From the equation (2), it is clear that

(1) $n \propto \frac{1}{l}$ if T and m are constant i.e. the frequency of vibration of a given stretched string varies inversely as the length of the vibrating segment of the string under a constant tension. This is known as the *Law of Length.*

(2) $n \propto \sqrt{T}$ if l and m are constant i.e. the frequency of vibration of a given stretched string of a given length varies directly as the square root of the tension. This is known as the *Law of Tension.*

(3) $n \propto \frac{1}{\sqrt{m}}$ if l and T are constant i.e. the frequency of vibration of a stretched string varies inversely as the square root of mass per unit length for the given length of the string under constant tension. This is known as the *Law of Mass.*

The Law of Mass has two aspects—

For a uniform wire of circular cross-section of radius r and density ρ, the mass per unit length $= \pi r^2 . 1 . \rho = \pi r^2 \rho$.

Hence

$$n \propto \frac{1}{\sqrt{m}} \text{ i.e. } n \propto \frac{1}{\sqrt{\pi r^2 \rho}}$$

i.e. $n \propto \frac{1}{r}$ if ρ is constant and also $n \propto \frac{1}{\sqrt{\rho}}$ if r is constant i.e. under constant tension, for a given length of wire of a particular material, the frequency of vibration varies inversely as the radius of the wire. This is known as the *Law of Radius or the Law of Diameter.*

And also, under constant tension, for a given length of wire of constant thickness, the frequency of vibration varies inversely as the square root of the density of the material of the wire. This is known as the *Law of Density.*

Procedure. In a rough balance, weigh the hanger for suspending weights. Also test the exactness of the kilogram or half kilogram weights by weighing them in the rough balance nearest to a gramme. Suspend some weights on the hanger so that the tension is sufficient.

Now, in order to verify the laws of transverse vibrations proceed as follows—

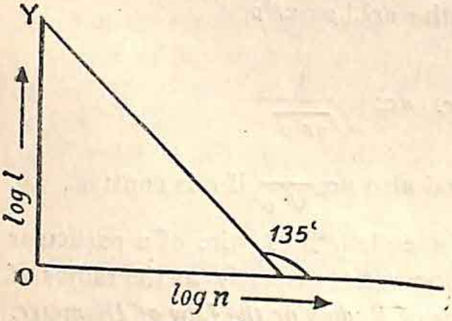
LAW OF LENGTH

(i) Take a tuning fork of known frequency. Strike it on a rubber pad, and press its stem against sonometer board, when a sound will be produced. Produce another sound by plucking the wire between the two movable bridges and see whether the two sounds produced are in unison. In general they will not be in unison. Bring about the unison between two sounds by moving one of the movable bridges when the beats previously heard just disappear.

(ii) Carefully examine the state of unison when on pressing the stem of a vibrating fork against the sonometer board, a small paper rider placed on the wire will be violently thrown down.

(iii) Measure the distance between the two movable bridges by the metre scale provided. Repeat the observation thrice and find out the mean value of the distances between the two movable bridges which will give the resonant length (l_1) for the fork (of frequency n_1) taken.

(iv) Keeping the tension constant, repeat the above procedure with tuning forks of other frequencies and note the length (l) in each case.



(Fig 3.9)

(v) Now show that $n_1l_1=n_2l_2=$ .... constant which will verify the Law of Length.

(vi) Plot a graph with n along x-axis and $\frac{1}{l}$ along y-axis. If it comes out to be a straight line passing through the origin, the above law is verified.

Next, plot another graph with log n on x-axis and log l on y-axis. If it comes out to be a straight line with slope equal to -1, the Law of Length is verified.

LAW OF TENSION

The verification of this law may be done by any of the following two methods—

(*a*) *Method involving the use of comparison wire.*

(i) Provide two bridges to the comparison wire. Apply a tension T_1 to the experimental wire of the sonometer. Now, setting the bridges under experimental wire conveniently apart, produce a sound of suitable pitch. Adjust the distance between the bridges under comparison wire until the sounds emitted by the two wires are in unison i.e. when the beats previously heard just disappear. Measure the distance l_1 between the two bridges under comparison wire.

(ii) Now change the tension applied to the experimental wire to T_2. Without altering the position of the bridges under experimental wire, adjust the distance between the two bridges under the comparison wire until the unison is obtained between the notes from the two wires. Note down this length l_2 of the comparison wire.

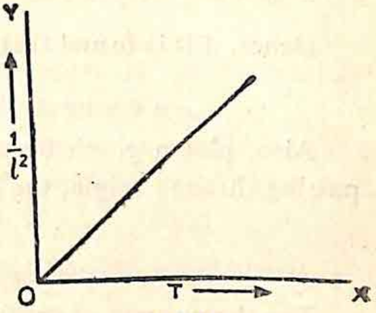
(iii) Repeat the above procedure, increasing the tension on the experimental wire in steps of one or half kilogramme and noting the length l of the comparison wire each time.

(iv) Now, show that $T_1 l_1^2 = T_2 l_2^2 = T_3 l_3^2 = \ldots$ constant

i.e. $\frac{1}{l^2} \propto T$

i.e. $\frac{1}{l} \propto \sqrt{T}$.

But from the Law of Length $n \propto \frac{1}{l}$.



(Fig. 3.10)

So, combining the two, we get $n \propto \sqrt{T}$.

Hence, if $T_1 l_1^2 = T_2 l_2^2 = T_3 l_3^2$ etc.....come out to be constant, the law is verified.

Also, plot a graph with T on x-axis and $\frac{1}{l^2}$ on y-axis. If it comes out to be a straight line passing through the origin, the law is verified.

(*b*) *Method involving the use of tuning fork.*

(i) Apply a certain tension T_1 to the experimental wire.

(ii) Allow the tuning fork to vibrate and adjust the distance between two bridges under experimental wire so that the note emitted by the segment, between the bridges, is in unison with that of the fork. Measure the distance l_1 between the two bridges.

(iii) Repeat the above procedure, increasing the tension to the experimental wire, in steps of one or half kilogramme and noting the length l between two bridges under experimental wire each time.

(iv) Now, show that $\sqrt{\frac{T}{l}}$ = constant in each case,

i.e. $l \propto \sqrt{T}$, when n and m are constant.

So again from the law of length, $l \propto \frac{1}{n}$ where T and m are constant.

Hence jointly,

$$l \propto \frac{\sqrt{T}}{n}, \text{ when } m \text{ is constant}$$

or $$n \propto \frac{\sqrt{T}}{l}, \text{ when } m \text{ is constant}$$

or $$n \propto \sqrt{T}, \text{ when } l \text{ and } m \text{ are constant.}$$

This is the Law of Tension.

Hence, if it is found that $\frac{\sqrt{T_1}}{l_1} = \frac{\sqrt{T_2}}{l_2} = \frac{\sqrt{T_3}}{l_3} = \ldots\ldots$

$=$ a constant, then, this law holds good.

Also, plot a graph between T and l^2. If it is a straight line, passing through origin, the law is verified.

LAW OF MASS

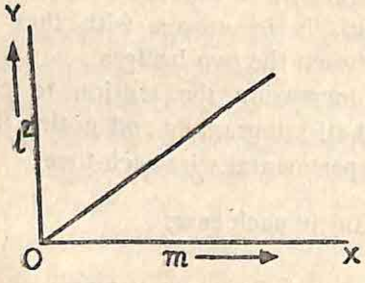
For the purpose of verifying the law of mass, again either of the following two methods may be employed.

(*a*) *Method involving the use of comparison wire.*

(i) Apply a certain tension of 3 or 4 kilogrammes to the experimental wire and place the bridges under it suitably apart.

(ii) Adjust the distance between the two bridges under the comparison wire until the notes emitted by the two segments of the two wires are in unison. Note the length l_1 of the comparison wire between the two bridges.

(iii) Take out the experimental wire. Weigh it in a sensitive balance and measure its length and hence find out the mass (m_1) per unit length of the experimental wire.



(Fig. 3.11)

(iv) Repeat the above procedure, taking the different experimental wires (i.e. mass per unit length being different) and finding that length of the comparison wire which emits sound of the same frequency as that of the sound emitted by a constant length of the experimental wire, in each case.

(v) Now, show that

$$\frac{l_1^2}{m_1}=\frac{l_2^2}{m_2}=\ldots=\frac{l^2}{m}=\text{constant in each case i.e. } l\propto\sqrt{m}.$$

But, since $n\propto\frac{1}{l}$,

so, $n\propto\frac{1}{\sqrt{m}}$ which is the Law of Mass.

Hence, if $\frac{l^2}{m}$ comes out to be constant in each case, the law is verified.

Plot a graph with m on x-axis and l^2 on y-axis. If it is a straight line passing through the origin, the law is verified.

(vi) Now, taking the different experimental wires of the same material but of differing radii r_1, r_2, r_3 etc. and performing the above procedure show that

$\frac{l_1}{r_1}=\frac{l_2}{r_2}=\frac{l_3}{r_3}=$ ....constant, which will verify the Law of Radius since $n\propto\frac{1}{l}$ and hence $n\propto\frac{1}{r}$.

(vii) Again, taking the different experimental wires of the same radius but of differing materials of density ρ_1, ρ_2, ρ_3 etc. and performing the above procedure, show that

$\frac{l_1^2}{\rho_1}=\frac{l_2^2}{\rho_2}=\frac{l_3^2}{\rho_3}$...constant i.e. $l\propto\sqrt{\rho}$ which will verify the Law of Density since $n\propto\frac{1}{l}$ and hence $n\propto\frac{1}{\sqrt{\rho}}$.

(*b*) *Method involving the use of tuning fork.*

(i) Apply a certain tension of 3 or 4 kilogrammes to the experimental wire (of mass m_1 per unit length) and adjust the distance between the two bridges under it until the sound emitted by the segment of the wire is in unison with that emitted by the tuning fork. Note the distance l_1 between the two bridges.

(ii) Repeat the above procedure with different experimental wires of differing mass per unit length. Keeping the tension the same in each case, find the distance l between the bridges under experimental wire.

(iii) Now, show that $l\sqrt{m}$ is constant in each case which will verify the Law of Mass as discussed above.

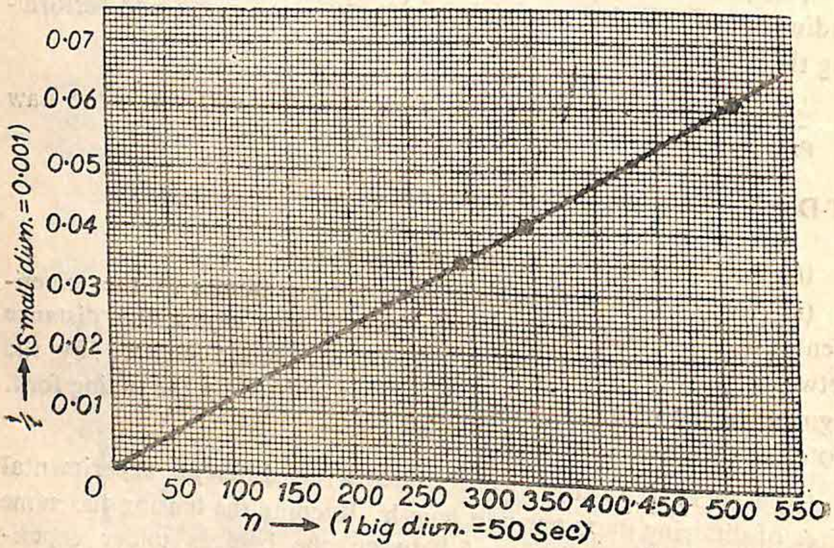
(iv) In a similar way, taking different experimental wires of the same material but of differing radii and of the same radius but of differing material, and performing the above operations, verify the Law of Radius and the Law of Density separately.

Observations and Calculations

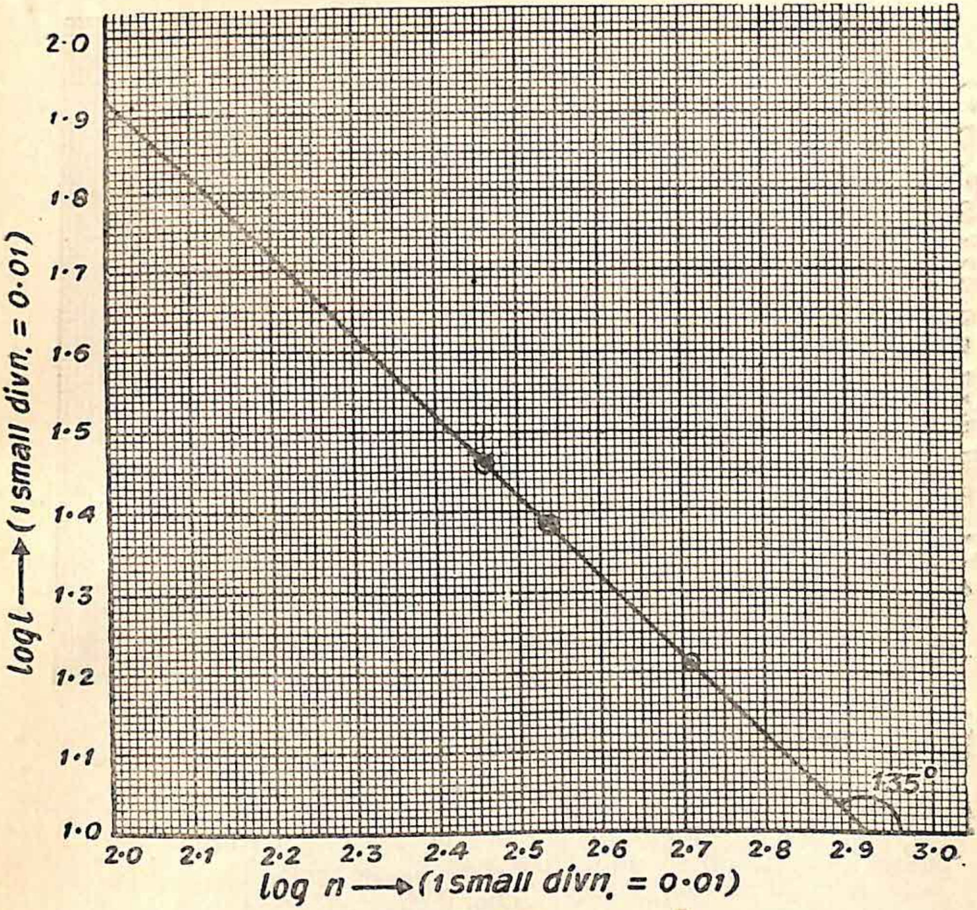
TABLE 1

Applied tension = 2500 × 980 dyne.

No. of obs.	Frequency (of tuning fork n/sec.	Reading of left bridge in (cm) a	Reading of right bridge in (cm) b	Difference $a-b=l$ (in cm)	$\frac{1}{l}$ cm^{-1}	$n\times l$	log n	log l
1	512	37·10	53·30	16·20	0·0617	8294·4	2·7093	1·2095
2	342	36·40	60·70	24·30	0·0412	8310·6	2·5340	1·3856
3	288	30·05	58·90	28·85	0·0347	8308·8	2·4594	1·4601



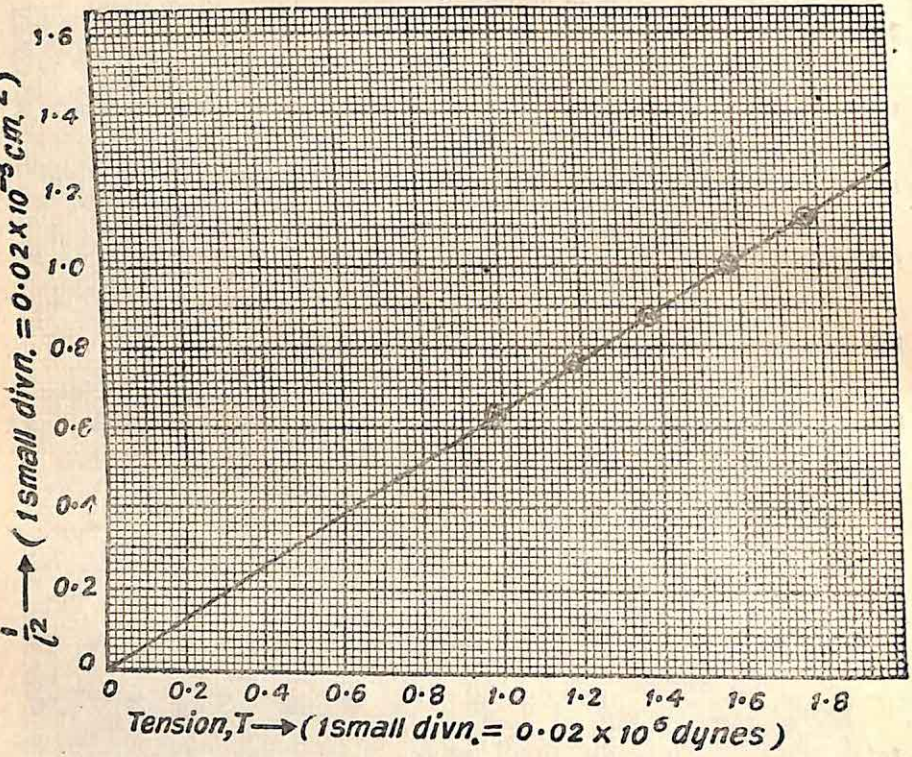
(Fig. 3.12)



(Fig. 3.13)

TABLE 2

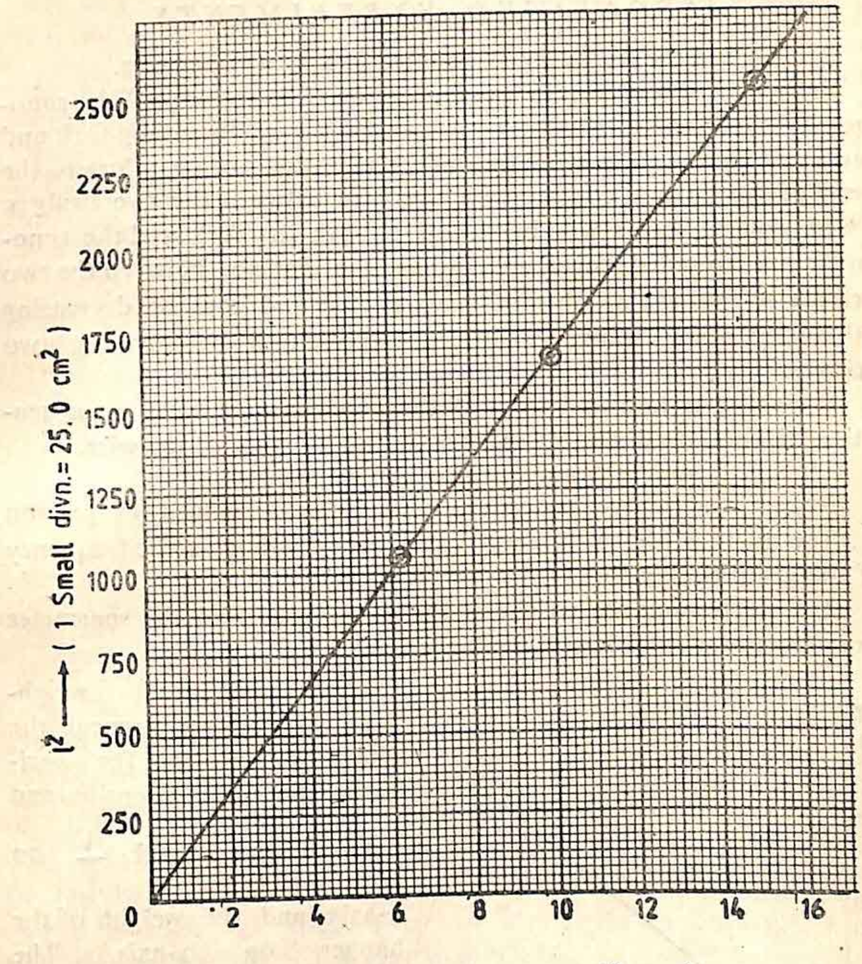
No. of obs.	Mass of Hanger + Wt. on hanger in (gm)	Tension of experimental wire in dyne	Length of auxiliary wire			l^2 (cm)	$\frac{1}{l^2}$	$T\times l^2$
			Reading of left bridge in (cm)	Reading of right bridge in (cm)	Difference $=l$ in (cm²)			
1	$1{\cdot}0\times10^3$	$0{\cdot}98\times10^6$	36·50	76·40	39·90	1592·0	$0{\cdot}6289\times10^{-3}$	$1{\cdot}5602\times10^9$
2	$1{\cdot}2\times10^3$	$1{\cdot}176\times10^6$	42·90	79·35	36·45	1328·6	$0{\cdot}7569\times10^{-3}$	$1{\cdot}5624\times10^9$
3	$1{\cdot}4\times10^3$	$1{\cdot}372\times10^6$	44·50	78·20	33·70	1135·7	$0{\cdot}8812\times10^{-3}$	$1{\cdot}5582\times10^9$
4	$1{\cdot}6\times10^3$	$1{\cdot}568\times10^6$	48·45	79·90	31·45	9891·0	$1{\cdot}0110\times10^{-3}$	$1{\cdot}5508\times10^9$
5	$1{\cdot}8\times10^3$	$1{\cdot}764\times10^6$	50·65	80·35	29·70	8821·0	$1{\cdot}337\times10^{-3}$	$1{\cdot}5560\times10^9$



(Fig. 3.14)

TABLE 3

No. of obs.	Linear density of wire m gm/cm	Length of auxiliary wire in cm				l^2	$\frac{l^2}{m}$
		Reading of left bridge a	Reading of right bridge b	Difference $(a-b)$	Mean length l		
1	$6{\cdot}20 \times 10^{-3}$	75·60	43·35	32·25	32·33	1045·23	$1{\cdot}6859 \times 10^5$
		68·45	36·05	32·40			
2	$9{\cdot}98 \times 10^{-3}$	78·90	38·00	40·90	40·95	1676·90	$1{\cdot}6803 \times 10^5$
		67·50	26·50	41·00			
3	$14{\cdot}98 \times 10^{-3}$	81·50	31·25	50·25	50·20	2520·04	$1{\cdot}6836 \times 10^5$
		80·00	29·85	50·15			



(Fig. 3.15)

Precautions. (i) The pulley of the sonometer should be provided with ball-bearings to minimise the friction.

(ii) The above experiment should be performed with fairly large tension so that *l* may be large and hence error in its measurement may be small. But, care should be taken that it should not exceed half the breaking weight for the wire.

(iii) For the wire to emit its fundamental note, it should be plucked or bowed in the middle of the two bridges under the wire.

(iv) Do not use finger nails to pluck the wire as it is likely to give harmonics or overtones.

ASSOCIATED EXPERIMENTS

1. To find the frequency of a tuning fork by a Sonometer.

Hints. Apply a certain known tension T to the wire of the sonometer. Striking on a rubber pad, excite the given tuning fork and run it along the wire with one of its vibrating prongs (close to the bend of the fork) in contact with the wire between the two bridges.

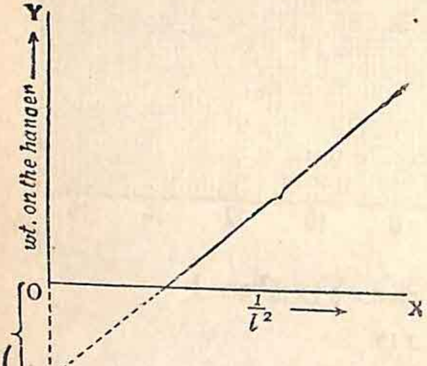
In general, beats will be heard if both the fork and the sonometer are sounded together. Adjust the distance between the two bridges so that the number of beats per second goes on decreasing till finally beats disappear. Measure the length between the two bridges.

Weighing a known length of the experimental wire, in a sensitive balance, find out the mass m per unit length of the wire.

Thus, l, T and m being known n can be evaluated.

Repeat the above procedure with different values of tension T. The average of the different values of n will give the frequency of the given tuning fork.

2. To determine the weight of the hanger used with the sonometer experimental wire without weighing it.



(Fig. 3.16)

Hints. Without weighing the hanger, repeat the above experiment for verifying the law of tension and draw a graph with $\frac{1}{l^2}$ on x-axis and the weight of the hanger on y-axis. The intercept on y-axis, below the origin will given the weight of the pan.

3. To determine the density of the material of the given wire without weighing it in a balance using a sonometer.

Hints. Take a tuning fork of known frequency and using the given wire as the experimental wire, repeat the above experiment No. (2) (in associated experiment section). Now, from the formula $n=\frac{1}{2l}\sqrt{\frac{T}{m}}$ calculate the linear density m. Measure the radius of the wire with a screw gauge and then calculate the density ρ from the formula $m=\pi r^2\rho$.

4. To compare the diameters of the two given wires of the same material with the help of a sonometer.

Hints. Use one of the given wires as experimental wire. Apply certain tension to it and place the bridges under it suitably apart. Now, adjusting the distance between the two bridges under comparison wire find the length l_1 of the comparison wire which emits sound of the same frequency as that of the sound emitted by a given length of the experimental wire. Let its mass per unit length be m_1.

Now, repeat the above procedure with the second wire and find the length l_2 of the comparison wire.

Now, if d_1 and d_2 be the diameter of the two wires, then, from the law of diameter (or law of radius)

$$\frac{l_1}{d_1}=\frac{l_2}{d_2}$$

i.e. $\frac{d_1}{d_2}=\frac{l_1}{l_2}$ from which compare the diameters of the two wires.

5. To compare the densities of brass and steel, using wires of these materials and a sonometer.

Hints. Using the brass wire (of density say ρ_1), repeat the above experiment for verifying the law of mass and find the length l_1 of the comparison wire which emits sound in unison with that emitted by a constant length of the experimental wire. Next, repeat the same operation with steel wire as the experimental wire and find the length l_2 of the comparison wire.

Now, from the law of density

$$\frac{l_1^2}{\rho_1}=\frac{l_2^2}{\rho_2}$$

i.e. $\frac{\rho_1}{\rho_2}=\frac{l_1^2}{l_2^2}$ from which compare the densities of brass and steel.

6. To find the frequency of the given tuning fork with the sonometer and then to find the unknown load supplied.

Hints. For finding the frequency of the given tuning fork—see the Associated experiment No. 2. When the frequency of the tuning fork is known, repeat the above experiment for verifying the law of tension and determine the mean value of the constant Tl^2. Also plot a graph $\left(T-\frac{1}{l^2}\right)$.

Now, remove all the loads and suspend the unknown load W from the hanger. Determine the length L of the comparison wire which produces sound in unison with that of the experimental wire of constant length. Now, divide the constant Tl^2 by L and obtain the weight of the supplied load.

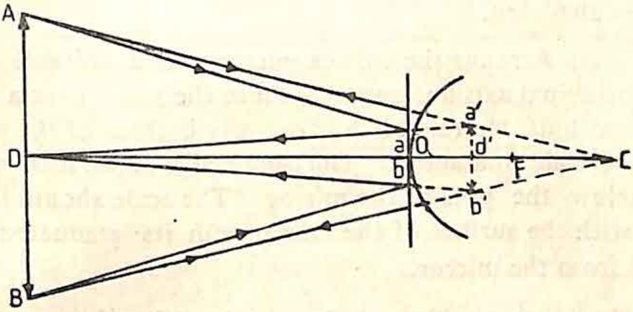
Also, from the graph, find the weight corresponding to the length L. Compare the two values.

□□□

4. OPTICS

EXPERIMENT 1. To determine the focal length of a convex mirror by Kohlrausch's method.

Apparatus. A half metre scale, a metre scale, telescope, tape, plumb line, and the convex mirror.



$OD=-u$
$AB=L$
$a'b'=l'$
$ab=l$
$Od'=+v$

(Fig. 4.1)

Theory. Let a large object like a metre scale be placed horizontally in front of the convex mirror and let A and B be two marks on the object. On account of reflections of the rays incident from the object to the mirror, as shown in the figure given above, the virtual image $a'b'$ of the object AB is formed behind the mirror. $a'b'$ appears to be projected on another scale placed in contact with the surface of the mirror. Let its length as read on this scale by an eye placed at D be l'.

Hence, from the geometry of the figure,

$$\frac{l'}{l}=\frac{|u|+|v|}{|u|} \qquad \cdot\cdot \quad (1).$$

Also we have the relation for u, v and r (the radius of curvature) given by

$$\frac{1}{+|v|}+\frac{1}{-|u|}=\frac{2}{r} \qquad \cdot\cdot \quad (2),$$

and the magnification $\quad \dfrac{l'}{L}=\dfrac{|v|}{|u|} \qquad \cdot\cdot \quad (3).$

$\therefore$ Dividing (1) by (3),

$$\frac{L}{l}=\frac{|u|+|v|}{|v|}=\frac{|u|}{|v|}+1$$

or $$\frac{|u|}{|v|}=\frac{L}{l}-1, \text{ or } \frac{1}{|v|}=\frac{L-l}{|u|\,l} \qquad \ldots (4).$$

Combining (4) and (2),

$$r=+\frac{2\,|u|\,l}{L-2l}.$$

Hence, if l and L are read on the scales, and u is measured by a tape, r can be calculated.

Procedure. (i) Arrange the convex mirror over a suitable stand and make its principal axis horizontal. Place the stand over a table. Also arrange a half metre scale horizontally in front of the mirror by clamping the scale to a stand. The upper edge of the scale should be slightly below the pole of the mirror. The scale should in fact be in contact with the surface of the mirror with its graduated face pointing away from the mirror.

(ii) Now take another table and place it about 2 to 3 metres away from the first table. Arrange the metre scale horizontally by clamping it to a stand. The graduated face of the scale should face the mirror and its upper edge should be slightly above the axis of the mirror. Arrange two paper flaps in this scale separated from each other by 50 cm to mark two points A and B.

(iii) Place the telescope over the second table with its objective above or below the metre scale as may be found convenient to see images of the flaps formed in the mirror and also the graduations of the half metre scale near the mirror. As the images of the flaps and the half metre scale are not at the same place, both of these cannot be in focus simultaneously when seen by the telescope. Hence adjust the telescope such that both of these are equally out of focus. As both images of the flaps and the graduations of the half metre scale are out of focus, there will be parallax between them. Hence the readings of the positions of images of the flaps (readings of the positions a and b) should be taken keeping the eye fixed at one position. This means that the positions a and b should be read and recorded at a time, and not one by one by removing eye after taking the reading of one position and then fixing the eye to another position. The reading of a and b gives l. As the flaps on the metre scale are separated by 50 cm, the value of $L=50$ cm. The distance between the metre scale and the convex mirror should be measured by a tape. This will give u.

(iv) Adopting the procedure as described above, readings of *ab* i.e., *l*, should be taken by making $L=60$ cm and 70 cm also, keeping the value of *u* fixed. The different values of *l* corresponding to the values of 50 cm, 60 cm and 70 cm of *L* should be tabulated, and then the value of *r* should be calculated from every set of data.

(v) The experiment should be repeated for at least three values of *u*, and the mean value of *r* determined.

Observations and Results

No. of obser-vation	Object dis-tance *u* in cm	Length of the object, *L* in cm	Apparent size of the image, *l* in cm			$r=\frac{2\mid u\mid l}{L-2l}$ in cm	Mean *r* in cm	Mean *f* in cm
			Reading of one end	Reading of the other end	Diffe-rence			
1	$-217{\cdot}9$	(i) 40	24·00	26·55	2·55	+31·8	+31·33	+15·66
		(ii) 50	23·70	26·90	3·20	+32·0		
		(iii) 60	23·40	27·10	3·70	+30·6		
2	$-233{\cdot}7$	(i) 40	24·70	27·10	2·40	+33·2		
		(ii) 50	24·50	27·45	2·95	+31·2		
		(iii) 60	24·20	27·70	3·50	+30·8		
3	$-248{\cdot}4$	(i) 40	26·95	24·70	2·25	+30·9		
		(ii) 50	24·90	27·20	2·75	+30·8		
		(iii) 60	24·10	27·40	3·30	+30·7		

r in m $=0{\cdot}3133$, and *f* in m $=0{\cdot}1566$.

Precaution. As the formula used holds properly for large values of *u*, it is advised that the distance between the mirror and the metre scale with flaps should be large in comparison with the radius of curvature of the mirror.

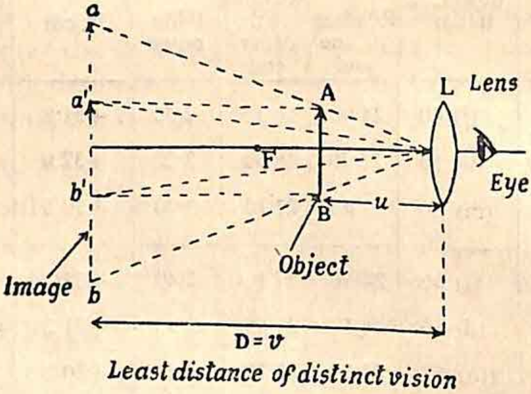
Note. (i) The radius of curvature of concave mirror can also be found by Kohlrausch's method.

(ii) Kohlrausch's method can also be used to find the radii of curvature of small objects having small radii of curvature. The experiment in that case will have to be performed in a dark room where two small sources of light should be used. Measurement of l may have to be taken with a travelling microscope.

EXPERIMENT 2. To determine the magnifying power of a convex lens (Simple Microscope).

Apparatus. Two half metre scales (preferably paper scales), a small plane mirror fixed to a 45° inclined wooden or cork base with a small circular unsilvered aperture at its centre, a ring clamped to stand, an electric lamp, and the convex lens.

Theory. The ratio of the angle subtended at the eye by the image formed by a convex lens to the angle subtended at the eye by the object when supposed to be situated at the least distance of distinct vision, provided the eye is placed close to the lens, gives the magnifying power of the lens.



(Fig. 4.2)

Referring to the figure given above, the magnifying power of the lens

$$= \frac{\text{Angle subtended by } ab \text{ at the eye}}{\text{Angle subtended at the eye by } AB \text{ when supposed to be placed at the same distance } D \text{ as } ab}$$

$$= \frac{\text{Angle subtended by } ab \text{ at the eye}}{\text{Angle subtended by } a'b' \ (=AB) \text{ at the eye}}$$

$$= \frac{ab/D}{a'b'/D} = \frac{ab}{a'b'} = \frac{ab}{AB} = \frac{|\,v\,|}{|\,u\,|}$$

where u and v are the object and image distance respectively. If

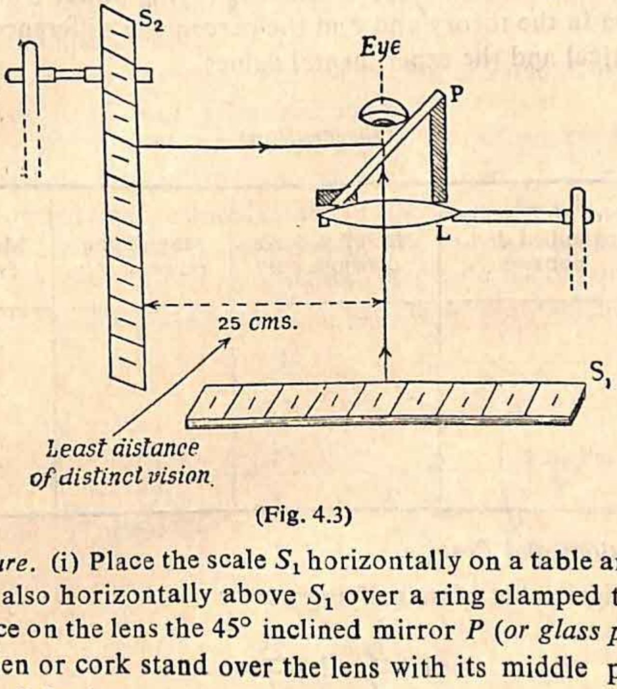
f be the focal length of the lens

$$\frac{1}{-|v|}-\frac{1}{-|u|}=\frac{1}{+|f|}, \text{ or } -1+\frac{|v|}{|u|}=\frac{|v|}{|f|}$$

$$\text{or } \quad -\frac{|v|}{|u|}=1+\frac{|v|}{|f|}=1+\frac{D}{f}.$$

$\therefore$ Magnifying power of the lens $=1+\dfrac{D}{f}$.

In the experimental determination of the magnifying power of the lens arrangements have to be made to transfer the object also to the position of the image formed by the lens with the help of the plane mirror. It is only then that the size of the image can be compared with the size of the object to obtain the magnifying power of the lens.



(Fig. 4.3)

Procedure. (i) Place the scale S_1 horizontally on a table and arrange the lens L also horizontally above S_1 over a ring clamped to a stand.

(ii) Place on the lens the 45° inclined mirror P (*or glass plate*) fixed on a wooden or cork stand over the lens with its middle point over the centre of the lens.

(iii) Arrange the other scale S_2 vertically on one side of the lens at a distance of about 25 cm from the axis of the lens with its face towards the mirror.

(iv) Now switch on the electric lamp to illuminate S_1 and S_2 and adjust the position of the lens by moving it up and down to see well defined magnified graduations of the scale S_1 when the eye is placed close to the plate P to look at the image of S_1. Also try to see simultaneously the image of scale S_2 formed by the mirror (or glass plate) at P. If necessary adjust the position of S_1 on the table so that the image of S_1 and that of S_2 are seen side by side. Finally adjust the position of L until there is no parallax between the magnified image of S_1 produced by the lens and the image of S_1 in the mirror at P.

(v) Images of S_1 and S_2 are now formed at the least distance of distinct vision. Note the number of divisions n' of the vertical scale S_2 that are seen to coincide with the number of divisions n of the magnified divisons of the scale S_1.

Calculate the magnifying power of the lens by dividing n' by n.

(vi) By taking different values of n repeat the observation at least three times, and find the mean magnifying power of the lens. Also calculate the theoretical value of the magnifying power from the relation given in the theory and find the percentage difference between the theoretical and the experimental values.

Observations

No. of observation	No. of S_1 scale magnified divisions $=n$	No. of S_2 scale divisions $=n'$	Magnifying power $=n'/n$	Mean Magnifying power
1				
2				
3				

Calculations and Results.

Theoretical value of magnifying power

$$=1+\frac{D}{f}=1+\frac{25}{f}=\ldots\ldots$$

(The value of f for this purpose may be determined by single pin method.)

Experimental value of magnifying power $=\ldots\ldots\ldots$

Percentage difference $=\ldots\ldots\ldots$

Note. (i) Due to spherical aberration there may be some difficulty in avoiding parallax between the reflected image of S_2 and the magnified image of S_1. To avoid this trouble it is suggested that peripheral portion of the lens which causes spherical aberration should be covered by a piece of black paper leaving only the central portion of the lens to be used for image formation.

(ii) A close examination of the theory of the experiment shows that the experimental observation should be made by keeping the eye quite close to the lens.

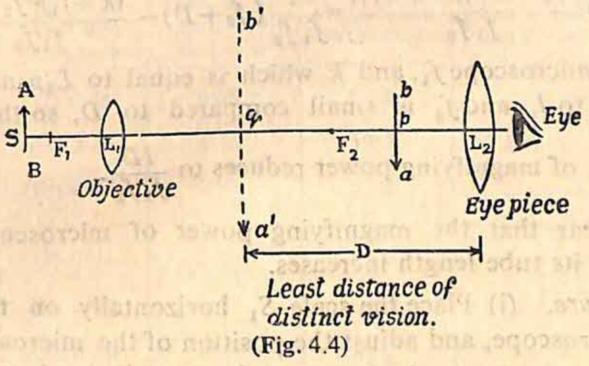
(iii) The image formed by the lens is virtual and magnified and it is positioned between the focal point and the optical centre of the lens.

EXPERIMENT 3. **To determine the magnifying power of a microscope.**

Apparatus. Two half metre scales (preferably paper scales), a 45° inclined small plane mirror with a circular unsilvered small aperture at its centre mounted on a wooden or cork base, lamp, a metre scale, and the microscope.

Description. MICROSCOPE : See the section "Some Common Instruments" in the General Physics chapter.

Theory. An object *AB* placed a little away from the focal point of the objective of the microscope has its magnified, real and inverted image *ab* formed by it inside the tube of the microscope at such a place between the eye-piece of the microscope and the focal point of the eye-piece that the eye-piece forms the final image *a′b′* of the object at the least distance of distinct vision of an eye placed close to the eye-piece.



(Fig. 4.4)

The magnifying power of the microscope will be, according to the definition given in expt. 2,

$$\frac{a'b'}{D} \Big/ \frac{AB}{D} = \frac{a'b'}{AB} = \frac{a'b'}{ab} \cdot \frac{ab}{AB}.$$

But $\frac{ab}{AB}=\frac{L_1p}{L_1s}=\frac{l-L_2p}{L_1s}$, where $l=$ tube length of the microscope.

Let f_1 and f_2 be the focal lengths of L_1 and L_2 respectively. We have then the relation

$$\frac{1}{+L_1p}-\frac{1}{-L_1s}=\frac{1}{+f_1}, \text{ or } \frac{1}{l-L_2p}+\frac{1}{L_1s}=\frac{1}{f_1}$$

or $\frac{1}{L_1s}=\frac{l-L_2p-f_1}{f_1(l-L_2p)}$ for the objective, for the eye-piece,

$$\frac{1}{-D}-\frac{1}{-L_2p}=\frac{1}{f_2}, \text{ or } L_2p=\frac{f_2D}{f_2+D}=\text{a constant}=k.$$

Hence $$\frac{ab}{AB}=\frac{l-L_2p}{L_1s}=\frac{(l-L_2p)\,(l-L_2p-f_1)}{f_1(l-L_2p)}$$

$$=\frac{l-k-f_1}{f_1}.$$

Further, as has been shown in expt. No. 3,

$$\frac{a'b'}{ab}=1+\frac{D}{f_2}.$$

The magnifying power of the microscope

$$=\left(1+\frac{D}{f_2}\right)\left(\frac{l-k-f_1}{f_1}\right)$$

$$=\frac{(f_2+D)\,(l-k-f_1)}{f_1f_2}=\frac{l}{f_1f_2}(f_2+D)-\frac{(k+f_1)(f_2+D)}{f_1f_2}.$$

For a microscope f_1, and k which is equal to L_2p are very small compared to l, and f_2 is small compared to D, so that the above expression of magnifying power reduces to $\frac{lD}{f_1f_2}$.

It is clear that the magnifying power of microscope increases linearly as its tube length increases.

Procedure. (i) Place the scale S_1 horizontally on the platform of the microscope, and adjust the position of the microscope on its vertical support to see the image of the scale distinctly through it.

(ii) Place on the eye-piece of the microscope the 45° inclined mirror (or glass plate) fixed on a wooden stand or cork with its middle part on the centre of the eye-piece as in Expt. 2.

(iii) Arrange the other scale S_2 vertically on one side of the microscope at a distance of about 25 cm from the microscope tube with its face towards the microscope as in Expt. 2.

(iv) Now switch on the electric lamp to illuminate S_1 and S_2 and bring your one eye very close to the 45° inclined mirror placed over the eye-piece to see the magnified image of the divisions of the scale S_1 and the reflected image of the scale S_2 simultaneously. If necessary adjust the position of the scale S_1 to see the image of S_1 and S_2 side by side. Finally adjust the microscope by moving it up or down until there is no parallax between the image of S_1 and S_2.

(v) Note the number of divisions n' of the vertical scale S_2 that are seen to coincide with the number of divisions n of the magnified divisions of the scale S_1.

Calculate the magnifying power of the Microscope by dividing n' by n.

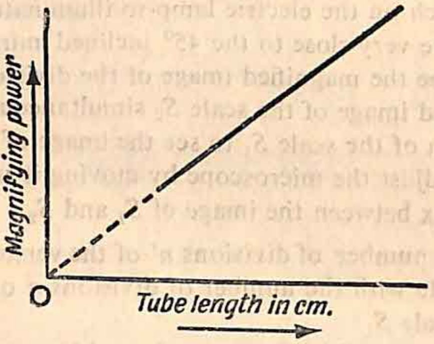
(vi) By taking different values of n, repeat the observations at least three times, and find the mean mangnifying power of the Microscope. Measure the length of the microscope tube (distance between the objective and the eye-piece).

(vii) By a similar process as described above measure the Magnifying power of the Microscope at its different tube lengths (at least ten) and plot a graph with tube length as x-axis and Magnifying power as y-axis.

Observations

No. of observation	No. of S_1 scale divisions$=n$	No. of S_2 scale divisions$=n'$	Magnifying power$=n'/n$	Mean Magnifying power	Tube length in cm
1	(i) 0·05	2·96	59·2	59·3	14·7
	(ii) 0·08	4·76	59·5		
	(iii) 0·10	5·96	59·3		
2	(i) 0·04	2·48	62·0	62·1	15·2
	(ii) 0·06	3·37	62·1		
	(iii) 0·10	6·22	62·2		
⋮					
10					

Graph. Draw a graph with tube length as x-axis and magnifying power as y-axis. This will be a straight line.



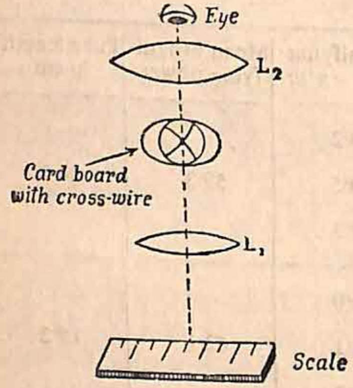
(Fig. 4.5)

Note. The graduation mark on the scale S_1 will be very much magnified by the microscope. It is, therefore, advised to count the number of divisions of S_1 between the edges only of the graduation marks of the image of S_1.

ASSOCIATED EXPERIMENTS

1. To set up a microscope and to determine its magnifying power.

Hints. Three rings should be clamped to a stand one above the other. A millimetre scale should be placed over the platform of the stand. A lens of short focal length (about 3 cm) should be placed on the lower ring and its position should be adjusted until a real, inverted and magnified image of the scale graduations is seen by the eye situated above the lens. Now a card-board should be taken. A hole should be punched in it and a pair of fine threads should be fixed over the hole with wax to make a cross. This card-board should be placed over the middle ring and its position adjusted until there is no parallax between the image of the scale and the cross-wire. Now a lens of large focal length (about 7 cm) should be placed over the top ring and its position should be adjusted by raising from a position close to the cross-wire upwards until a



(Fig. 6)

distinct image of the scale and the cross-wire is seen. The microscope is thus set up. Its magnifying power may be measured by the process as decribed in expt. No. 2.

EXPERIMENT 4. **To determine the magnifying power of a telescope focussed for infinity (Angular Magnification of a telescope).**

Apparatus. A slit made in a circular plate capable of being fitted to the tube of the telescope, a plumb line, cathetometer microscope, and the telescope.

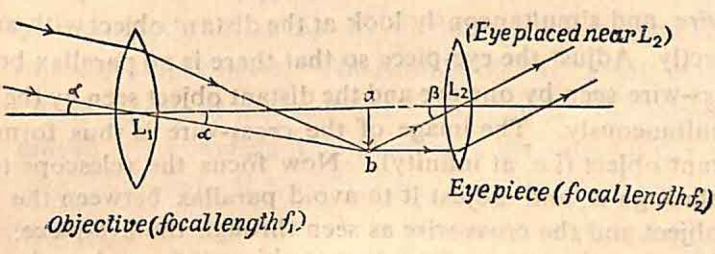
Description. (i) TELESCOPE.

See the section, "Some Common Instruments" in General Physics Chapter.

(ii) CATHETOMETER MICROSCOPE.

See the section, "Some Common Instruments' in General Physics Chapter.

Theory. When a telescope is focussed for infinity (i.e. to see a distant object), its objective forms the real and inverted image of the object at its focal plane. As the focal planes of the objective and the eye-piece under this type of focussing are coincident the eye-piece forms the final image of the object at infinity.



(Fig 4.7)

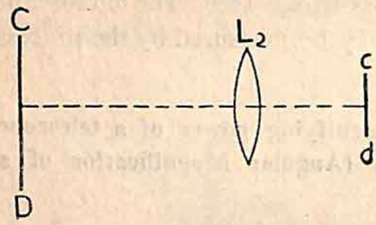
The magnifying power of a telescope is defined as

$$M = \frac{\text{angle subtended at the eye by image at infinity}}{\text{angle subtended at the eye by object at infinity}}.$$

From the above figure it is, therefore, clear that

$$M = \frac{\beta}{\alpha} = \frac{ab}{L_2a} \Big/ \frac{ab}{L_1a} = \frac{ab}{f_2} \cdot \frac{f_1}{ab} = \frac{f_1}{f_2}.$$

The magnifying power of the telescope is also called the angular magnification of the instrument.



(Fig. 4.8)

If the objective of the telescope is removed, and a slit CD is inserted in its place, the eye-piece L_2 forms the image cd of the slit. The distance of the slit from L_2 will be $|u| = f_1 + f_2$ (length of the telescope) and if the image distance $= v_1$ then

$$\frac{1}{+|f_2|} = \frac{1}{+|v|} - \frac{1}{-|u|}, \text{ or } \frac{1}{f_2} = \frac{1}{v} + \frac{1}{u}$$

or
$$\frac{u}{v} = \frac{v}{f_2} - 1 = \frac{u-f_2}{f_2} = \frac{f_1+f_2-f_2}{f_2} = \frac{f_1}{f_2}$$

and since
$$\frac{u}{v} = \frac{CD}{cd}.$$

∴ Magnifying power of the telescope focussed for infinity

$$= \frac{f_1}{f_2} = \frac{CD}{cd}.$$

Procedure. (i) Pick up a distant object like an electric pole and direct the telescope towards it. Do not focus the telescope to see the object. Look through the eye-piece of the telescope with one eye to see the cross-wire, and simultaneously look at the distant object with another eye directly. Adjust the eye-piece so that there is no parallax between the cross-wire seen by one eye and the distant object seen by the other eye simultaneously. The image of the cross-wire is thus formed at the distant object (i.e. at infinity). Now focus the telescope to see object through it, and adjust it to avoid parallax between the image of the object and the cross-wire as seen through the eye-piece. After this adjustment the image of the distant object is formed on the object itself. This type of adjustment is called the normal adjustment of the telescope.

(ii) Now unscrew the objective of the telescope out of its tube and replace it by the slit taking care to make it vertical. Arrange a cathetometer microscope behind the eye-piece of the telescope, with its axis in line with the axis of the telescope. Keeping your eye near the eye-piece of the cathetometer focus it to see the image of the slit formed by the eye-piece of the telescope taking care to avoid parallax between the image and the vertically arranged eye-piece scale of the cathetometer. Measure the length of the image in terms of the cathetometer eye-piece divisions. Let this be p. Repeat this measurement at least three times and find mean p.

(iii) Now turn the telescope to bring the slit in front of the cathetometer, and focus the slit. Looking through the cathetometer bring one of the horizontal edges of the slit as seen through the cathetometer over a particular graduation mark of the eye-piece scale of the cathetometer, and take the reading of this position on the vertical scale at the neck of the cathetometer. Move up the microscope to bring the other horizontal edge of the slit over the same graduation of the eye-piece scale, and take the reading of this position also on the vertical scale. Take the difference between the two readings. This will give P. Repeat this measurement at least three times and find mean P.

(iv) To calibrate the cathetometer eye-piece scale, the instrument is first of all levelled with the help of its levelling screws and the spirit level placed at its top. A plumb line is then focussed by it and its eye-piece scale is arranged vertically by adjusting it along the image of the plumb line. A pin is arranged vertically over a stand and focussed by the microscope. The tip of the pin is brought on a division mark of the eye-piece scale. The reading of this position is taken on the vertical scale at the neck of the instrument. The microscope is then moved up counting the number of divisions of the eye-piece scale passing through the tip of the image of the pin. Let N divisions pass through and then take the reading of this new position on the same vertical scale. Find the difference between the two vertical scale readings, and divide it by N to find the value of each division of the microscope eye-piece scale. Let this be n. Repeat this determination at least three times and find mean n.

(v) Now calculate the length of the image of the slit formed by the eye-piece. This will be $cd=np$. Finally calculate the value of the magnifying power of the telescope.

Observations

(i) *Determination of p.*

No. of observation	Length of the image in terms of the eye-piece scale = p	Mean p
1	57·5	57·0
2	57·0	
3	56·5	

(ii) *Determination of CD.*

No. of observation	Vertical scale reading for upper end of the slit	Vertical scale reading of the lower end of the slit	Length of the slit = CD	Mean CD
1	3·76 cm	1·82 cm	1·92 cm	
2				
3				

(iii) *Calibration of Cathetometer eye-piece scale.*

No of observation	Vertical scale reading for an eye-piece scale mark	Vertical scale reading after N divisions of eye-piece scale have moved	Differences between two vertical scale readings	N	Value of each division (n)
1	3·73 cm	3·93 cm	0·20 cm	50	0·004 cm
2					
3					

Mean value of $n = \ldots.$

Calculations and Results.

$cd = np = \ldots\ldots\ldots$

$CD = \ldots\ldots\ldots\ldots\ldots\ldots$

$\therefore$ Magnifying power $= \frac{CD}{cd} = \frac{CD}{np} = \ldots$.(experimental value).

Theoretical value of magnifying power $= f_1/f_2 = \ldots\ldots.$

Percentage difference between the two values $= \ldots\ldots.$

Note. (i) It is advisable to perform this experiment out-doors in a well lighted space. The experiment may also be performed in a room by illuminating the slit with the light from a milky electric bulb.

(ii) The axis of the telescope and the cathetometer must be brought nearly in one line and the cathetometer microscope should be moved backwards from the eye-piece of the telescope to see the image of the slit.

ASSOCIATED EXPERIMENTS

1. To set up a telescope and to determine its magnifying power.

Hints. Take two lenses : one of focal length about 5 cm to be used as the eye of the telescope, and the other of focal length about 30 cm to be used as the objective. Arrange these two lenses on two vertical stands, and adjust their centres to have equal height. Now take a card-board and punch a hole in it. Across the hole arrange two fine wires to form cross-wire. Mount this arrangement over another stand making height of the cross-wires also equal to the centres of the lenses. Now put the cross-wire near the lens of short focal length only and adjust the position of the lens such that there is no parallax between the image of the cross-wires as seen through the lens by one eye and a distant object like an electric pole seen simultaneously by the other eye directly. After this adjustment bring the lens of large focal length in front of the cross-wire, and adjust its position until there is no parallax between the cross-wire and the image of the distant object seen by the eye placed behind the lens of short focal length (eye-piece). After this adjustment a telescope is set up with a normal adjustment. The magnifying power of this telescope may be determined by the method described in Expt. 4, and this may be checked up by dividing the value of focal length of the objective by the value of focal length of the eye-piece. Use the same tables for observation as for the expt. 4.

EXPERIMENT 5. To determine the magnifying power of a telescope focussed for different distances (Transverse magnification produced by the telescope).

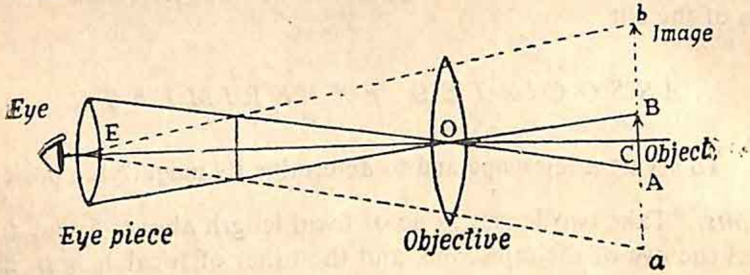
Apparatus. A large scale (about two metres long with its divisions painted alternately black and white), a tape, and the telescope.

Theory. Let the telescope be adjusted to see an object placed at a finite distance in such a way that the image is found on the object itself. In such a condition,

Magnifying power, M, of the telescope

$$=\frac{\text{Angle subtended by the image at the eye}}{\text{Angle subtended by the object at the eye}}=\frac{\angle aEb}{\angle AEB}=\frac{ab/Ec}{AB/Ec}=\frac{ab}{AB}$$

= transverse magnification produced by the telescope.



(Fig. 4.9)

Procedure. (i) Arrange the large scale vertically and place the telescope near it over a stool. See the image of the scale through the telescope with your left eye and the scale with your right eye. Adjust the telescope so that there is no parallax between the image of the scale and the scale when they are simultaneously seen as advised above. The image of the scale is now formed at the same place where the scale is placed. Now count the number n' of the scale divisions seen directly by one eye that correspond to number n of the image of the scale seen by the other eye.

(ii) Repeat the above observation for three different values of n, say 2, 3, 4, and calculate M from these observations separately, and then find the mean value of M. Also note the distance D between the telescope and the scale with the help of the tape.

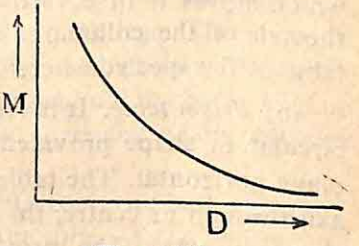
(iii) Measure the magnifying power M of the telescope by placing the telescope at different distances from the scale until it is found that the magnifying power becomes independent of the distance of the telescope from the source.

Observations

No. of observations	Distance of the telescope from the object, D in cm	No. of image divisions n	No. of object divisions n' coincident with n	Magnifying power
1	213	(i) 2 (ii) 3 (iii) 4	(i) 16 (ii) 24 (iii) 32	(i) 8·0 (ii) 8·0 (iii) 8·0 } Mean magnifying power $M=8\cdot00$
2 ⋮ 10	141	(i) 2 (ii) 3 (iii) 4	(i) 14·5 (ii) 22·0 (iii) 29·5	(i) 7·25 (ii) 7·33 (iii) 7·38 } Mean magnifying power, $M=7\cdot32$

Graph. Plot a graph with distance D on x-axis, and magnifying power M on y-axis.

Conclusions. Draw your own conclusions from the graph regarding the variation of M of the telescope with D.



(Fig. 4.10)

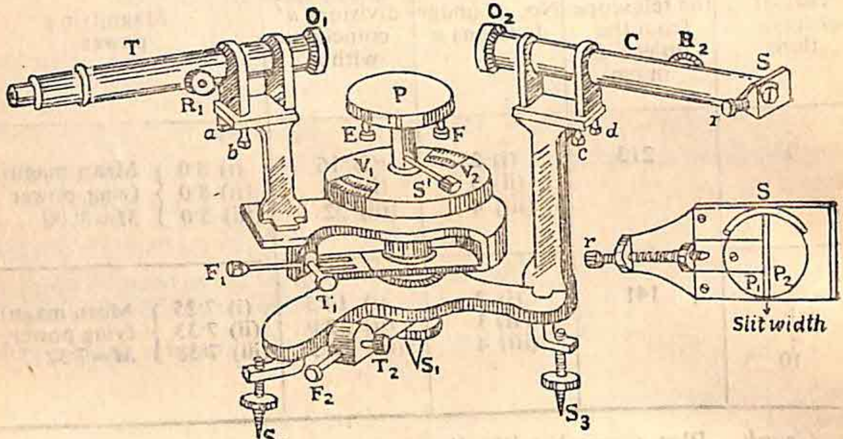
Note. The eyes must be properly exercised to see the object and its image each with one eye simultaneously. Once the eyes are set for this purpose, the experiment would not present only difficulty.

EXPERIMENT 6. To align (adjust) a prism spectroscope or spectrometer to obtain a pure spectrum.

Apparatus. Bunsen burner and solution of common salt or sodium vapour lamp, electric lamp, prism, spirit level, and the spectrometer.

Description. SPECTROMETER : It is an instrument widely used to produce spectrum of a source of light and to make measurements on the spectrum thus produced. The main parts of a spectrometer are (a) the collimator, (b) the prism table and (c) the telescope.

(a) *Collimator.* It consists of a tube of metal having an adjustable slit at one end and an achromatic convex lens at its other end. The length of the collimator tube can be adjusted by moving the slit by a rack and pinion arrangement to obtain a parallel beam of light emerging out of the lens when a source of light is placed in front of the slit. The collimator may also be made horizontal by a pair of screws which moves it in a vertical plane. The instrument maker adjusts the axis of the collimator to pass through the centre of the prism table of the spectrometer.



(Fig. 4.11)

(b) *Prism table.* It is the central part of the spectrometer which is circular in shape provided with three levelling screws to make its plane horizontal. The table is capable of being rotated about vertical axis through its centre; the rotation of the table can be read over a circular scale. The provision of a clamp and a tangent screw facilitates the fine movement of the table. As the prism is placed over it to perform experiments, it is called the prism table.

(c) *Telescope.* The telescope of a spectrometer is a small astronomical telescope having an achromatic convex lens as its objective. It uses a Ramsden's eye-piece. A rack and pinion arrangement helps to focus the instrument. It can be rotated in a horizontal plane about the vertical axis of the prism table, and the rotation can be read over the circular scale about the prism table. Fine movement of the telescope is obtained by the use of a clamp and a tangent screw. The rotation of the telescope in vertical plane is obtained by a pair of screws. The instrument maker adjusts the axis of the telescope to pass through the centre of the prism table in whatever position it is placed about the vertical axis through the centre of the prism table.

The spectrometer rests on a table on three legs. Most of the spectrometers have levelling screws attached to the legs to level the telescope.

Adjustments. The adjustments required in a spectrometer to observe a fine spectrum and make measurements are the following :

(a) *Levelling the telescope and the collimator.*

This amounts to making the axis of the telescope and the collimator horizontal and the axis of rotation of the prism table vertical. The following operations are needed to achieve this objective :

(i) Rotate the telescope and make it parallel to the two levelling screws of the legs of the spectrometer on the telescope side of the spectrometer. Place a spirit level on the telescope tube and adjust the two screws one by one of the legs to bring the bubble of the spirit level at the centre.

(ii) Now rotate the telescope by 180° from this position, and partly adjust the screws of the legs and partly the screws supporting the telescope to bring the bubble of the siprit level at the centre.

The operations (i) and (ii) are to be repeated several times until it is found that the bubble remains at the centre in both positions.

(iii) The telescope should now be rotated by 90° to make its axis perpendicular to the line joining the screws of the legs. The screw of the third leg may now be adjusted to bring the bubble of the spirit level at the centre. The operations (i) and (ii) should be checked again and if the levelling is disturbed it may be corrected again, and the operation (iii) checked again.

After these operations the axis of the telescope will be horizontal.

(iv) Now place the spirit level over the tube of the collimator and adjust the screws supporting this part of the instrument to bring the bubble of the spirit level at the centre. This makes the axis of the collimator horizontal.

Note. If there are no levelling screws attached to legs of the spectrometer, triangular wedges of iron may be used for the levelling purposes.

(b) *Adjustment of the collimator and telescope for parallel rays.*

SCHUSTER'S METHOD

Procedure. All spectrometer experiments are performed in the dark and hence it is advisable and convenient to make all adjustments in the dark room itself. It is by Schuster's method that the collimator and the telescope are adjusted for parallel rays in a dark room.

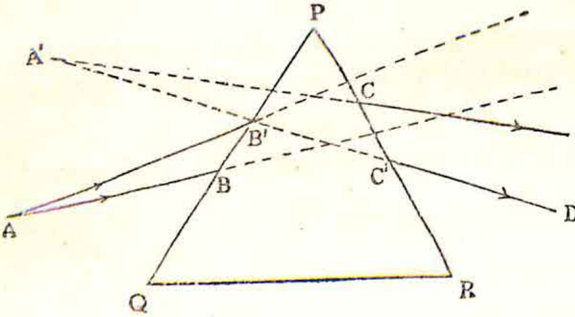
This method involves the following operations :

(i) The slit of the collimator is made narrow and illuminated by sodium light obtained from a sodium vapour lamp or by placing over a Bunsen burner flame an asbestos ring soaked with common salt solution. The prism table is then levelled by a spirit level and the prism is placed over it with the centre of its base at the centre of the prism table. The refracted image of the slit is seen by the naked eye by moving the eye towards the face of the prism through which the rays are expected to emerge. The telescope is then rotated and brought near the eye to receive the image. The prism table is rotated and image is followed by the telescope until the position of minimum deviation is reached.

(ii) After this the prism table is rotated to such a position where the angle of incidence of the light on the prism is much larger than the angle of incidence corresponding to the minimum deviation position. This is called the "slanting position" of the prism. The image is then received by the telescope in its position. The telescope receiving the image in this position is focussed to have a sharp image.

(iii) The prism is then rotated to such a position where the angle of incidence is much smaller than the angle of incidence corresponding to the minimum deviation position. This is called the 'normal position' of the prism. The image of the slit seen through the telescope in this position will be wider than the previous case. In this position, the image should be made sharp by focussing the collimator.

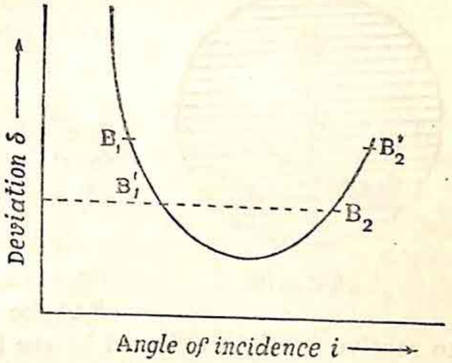
The operations (ii) and (iii) are to be repeated several times one after another until the image appears sharp in both slanting and normal positions of the prism. The collimator and the telescope then becomes focussed for parallel rays.



(Fig. 4.12)

Principle. In the incident — deviation curve (fig. 4.13) B_1 and B'_1 indicate the 'normal positions' of the prism. In the normal position, the incidence ray having a smaller angle of incidence suffers a greater deviation.

Hence the two emergent rays CD and $C'D'$ corresponding to the incident rays AB and $A'B'$ are more divergent than the incident rays, and the image A' of the point A is nearer the prism than the object (fig. 4.12).



(Fig. 4.13)

The points B_2 and B'_2 indicate the two 'slanting positions' of the prism on the i—δ curve. In the slanting position, the incident ray having a large angle of incidence suffers a greater deviation. Hence the two emergent rays CD and $C'D'$ corresponding to the incident rays AB and $A'B'$ are less divergent than the incident rays, and the image A' of the point A is more distant from the prism than the object.

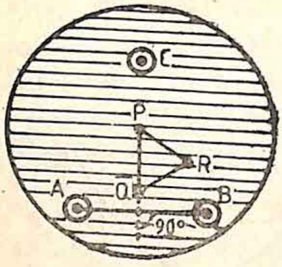
Suppose now that the prism is placed in the slanting position and the telescope is focussed to receive a sharp image, and then it is placed in the normal position. By focussing the collimator in this position the object A is made to move away from its original position in a direction away from the prism because the telescope has been focussed to receive rays in the slanting position when the image has been more distant from the prism than the object. Thus by repeating the process of focussing the telescope in the slanting position and the collimator in the normal position, the object A is gradually thrown more and more away from the prism. This amounts to gradually adjusting the collimator and the telescope towards the condition appropriate to parallel rays.

(c) *Optical levelling of the prism.*

The optical levelling of the prism necessitates the following operations :

(i) The telescope is set to receive the direct rays by bringing the intersection of the cross-wire of the telescope over the image of the slit seen through it. The telescope is then rotated by 90°.

(ii) The prism is then placed over the prism table with its refracting edge over the centre of the table, and a polished face of the



(Fig. 4.14)

prism perpendicular to the line joining two levelling screws (*A* and *B*) of the prism table. If one of the three levelling screws attached to the prism table be not capable of adjustment, then the face should be placed perpendicular to the line joining this screw and an adjustable screw.

(iii) Now the prism table should be rotated allowing the refracting edge *P* to be on the axis of the collimator to receive the light reflected by the face *PQ*. If the image of the slit received by the telescope is not in the middle of the field of view of the telescope, the two levelling screws *A* and *B* should be adjusted one after another until the centre of the image as seen through the telescope coincides with the intersection of the cross-wires.

(iv) The prism table should now be rotated to enable the telescope to receive the image of the slit formed by reflection from the face *PR*. The third levelling screw *C* should now be adjusted to bring the centre of the image at the intersection of the cross-wires. After this adjustment the prism is optically levelled over the prism table. The refracting faces of the prism are now parallel to the axis of rotation of the prism table.

It is advised that operation (iii) should be repeated again after operation (iv) to ensure that the image remains in the centre of the field of view after operation (iv) has been made.

After this adjustment the spectrometer is ready for experimental observations.

Note. (i) The following points should be carefully noted for successful adjustment of the spectrometer.

(a) The position and the height of the source of the light placed before the slit of the spectrometer should be properly adjusted to throw sufficient light over the slit. If necessary a converging lens may be used to concentrate the light over the slit.

(b) The slit of the spectrometer should be made as narrow as may be possible from the point of view of getting a visible fine image of the slit.

(c) Black cloth may be used to cut off all extra light coming from unwanted directions.

(d) A bulb of low wattage should be used to read the circular scale of the spectrometer.

(e) Reading on the circular scale should be taken by both verniers attached 180° apart.

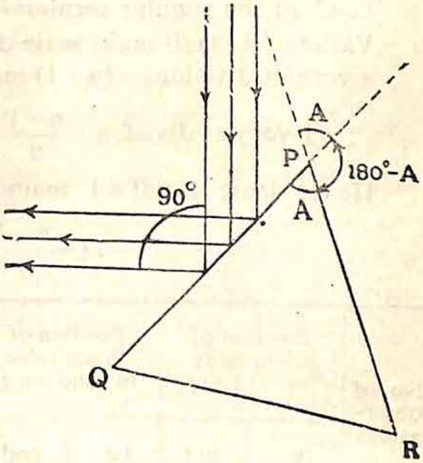
(ii) A costly spectrometer has a pair of verniers, attached to both the prism table and the telescope, that move as the prism table or the telescope is rotated, the main scale remaining fixed. This type of spectrometer is very convenient for all types of spectrometric measurements. However, relatively cheaper spectrometers, having a pair of verniers attached to the prism table only and the main scale attached to the telescope, are provided to students up to Degree level in a large number of laboratories. All spectrometric experiments will, therefore, be described in this book with reference to this type of spectrometer only.

EXPERIMENT 7A. **To measure the angle of a prism using a spectrometer.**

First Method :

Apparatus. Prism, spectrometer, sodium vapour lamp or sodium flame of Bunsen burner, spirit level, and electric lamp.

Theory. The prism PQR is set in a position where the ray reflected by the face PQ of the prism is making an angle of 90° with the incident ray. It is evident from the figure that, if A be the angle of the prism at the refracting edge P, the face PR will have to be rotated by $180° - A$ to bring it to the same position as the previous position of PQ in order that the reflected ray again makes an angle of 90° with the incident ray.



(Fig. 4.15)

Procedure. (i) Adjust the spectrometer following the procedure of adjustments described in Expt. 6.

(ii) Without keeping the prism on the prism table, view the image of the slit through the telescope and bring the image on the intersection of the cross-wires of the telescope. Read the position of the telescope with the help of the vernier scale attached to it, and then rotate it by 90°. Clamp the telescope in this position.

(iii) Now place the prism with the centre of its base over the centre of the prism table and its refracting edge, say *P*, on the axis of the collimator.

(iv) Now rotate the prism table until the reflected image formed by the face, say *PQ*, comes at the intersection of the cross-wires seen through the telescope. Tangent screw should be used for slow motion of the prism table. Note this position of the prism table on both verniers attached to the table.

(v) Now rotate the prism table again until the reflected image formed by the adjacent face, say *PR*, comes at the intersection of the cross-wires seen through the telescope left undisturbed in its previous position. Note this position of the prism table on the verniers attached to the table.

(vi) Find the difference between the two positions of the prism tables for the readings of the two verniers separately, and find the mean of these two. This mean when subtracted from 180° will give the angle of the prism, *A*.

(vii) Repeat the measurement of *A* at least three times and find the mean value of *A*.

Observations

L. C. of the angular vernier—

Value of 1 small main scale division $= \ldots. = 1s$

n vernier divisions $= (n-1)$ main scale divisions.

$$\therefore \quad 1 \text{ vernier division} = \frac{n-1}{n} \text{ main scale divisions.}$$

Hence least count = 1 main scale division − 1 vernier division

$$= 1s - \frac{n-1}{n} \times 1s = \frac{1}{n} \times 1s.$$

No. of observations	Position of Prism table for 1st image		Position of Prism table for 2nd image		Difference			Mea of all observations $=a$
	1s vernier	2nd vernier	1st vernier	2nd vernier	1st vernier	2nd vernier	Mean	
1								
2								
3								

Result. Angle of the Prism $= 180° - p = \ldots\ldots$

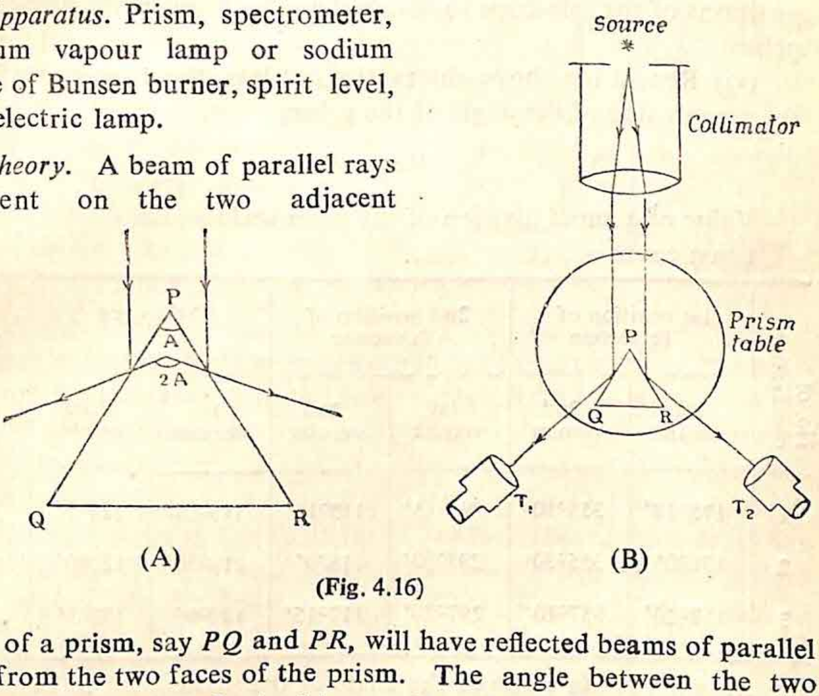
Note. In case of difficulty in getting the image inside the telescope the refracting edge of the prism facing the collimator may be shifted a little away towards the centre of the prism table. This will help in getting the image inside the telescope.

EXPERIMENT 7B. **To determine the angle of a prism using a spectrometer.**

Second Method :

Apparatus. Prism, spectrometer, sodium vapour lamp or sodium flame of Bunsen burner, spirit level, and electric lamp.

Theory. A beam of parallel rays incident on the two adjacent faces of a prism, say *PQ* and *PR*, will have reflected beams of parallel rays from the two faces of the prism. The angle between the two reflected beams thus obtained is equal to twice the angle between the two faces of the prism.



(A) (B)

(Fig. 4.16)

Procedure. (i) Adjust the spectrometer following the procedure of adjustments described in Expt. 6.

(ii) Place the prism on the prism table with its angle *P* which is desired to be measured on the centre of the prism table, and arrange it to point towards the collimator, the refracting edge being on the axis of the collimator. Clamp the prism table.

(iii) Rotate the telescope towards one face, say *PQ*, of the prism to receive the reflected image of the slit. When the image falls over the intersection of the cross-wires, clamp the telescope and note its position on the scale attached to the telescope with respect to the two verniers attached to the prism table.

(iv) Now rotate the telescope towards the other face, say *PR* of the prism, and receive the reflected image of the slit through the telescope. Adjust the telescope to bring the image of the intersection of the cross-wires on the image of the slit. Clamp the telescope in this position and read the positions of the telescope on the scale attached to it with respect to the two verniers attached to the prism table.

(v) Find the difference between the vernier readings in the two positions of the telescope to obtain the value of twice the angle of the prism.

(vi) Repeat the above observations at least three times, and find the mean value of the angle of the prism.

Observations

Value of 1 small division of the main scale = ...

Least count = ...

No. of observations	1st position of Telescope		2nd position of Telescope		Difference		Mean value of 2*A*
	1st vernier	2nd vernier	1st vernier	2nd vernier	1st vernier	2nd vernier	
1	175°18′	355°10′	295°15′	115°15′	119°57′	120°5′	119°59′·5
2	176°0′	355°50′	295°50′	116°0′	119°50′	120°0′	
3	177°20′	357°10′	297°20′	117°15′	120°0′	120°5′	

Result. Mean value of the angle of the prism = 59° 59′·8.

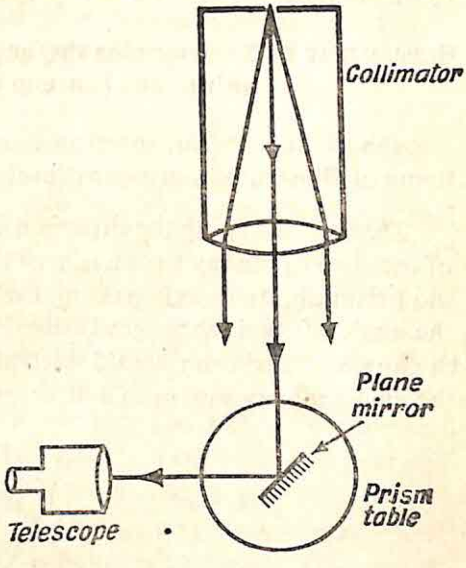
Notes. (i) It is advised that the image of the slit should be located first by the naked eye and then the telescope should be brought near the eye to see the image through it.

(ii) For fine adjustment of the position of the telescope, tangent screws should be used after clamping the telescope.

ASSOCIATED EXPERIMENT

1. To show that for a given incident ray if the reflecting surface is rotated by θ, the reflected ray is rotated through 2θ, using a spectrometer.

Hint. The experimental arrangements are exactly the same as those in Expt. No. 7 B. However, here a plane mirror should be placed over the prism table with the plane reflecting surface over the centre of the prism table. The incident beam is the beam coming along the axis of the collimator. Starting with a small angle of incidence over the reflecting surface, receive the reflected image at the intersection of the cross-wires as seen through the telescope. Note the position of the prism table by the two verniers attached to it. Now rotate the prism table by a known angle θ, say 10°. Note the positions of the verniers attached to the prism table. Rotate the telescope to receive the reflected image again on the intersection of the cross-wires. This will move the main scale attached to the telescope. Note this position of the telescope by reading the position of the verniers attached to it. The difference between the readings of the verniers before and after the rotation of the telescope will give the angle through which the reflected beam has been rotated. Take at least six observations for five different values of θ. Tabulate your observations in a table of the type given below :



(Fig. 4.17)

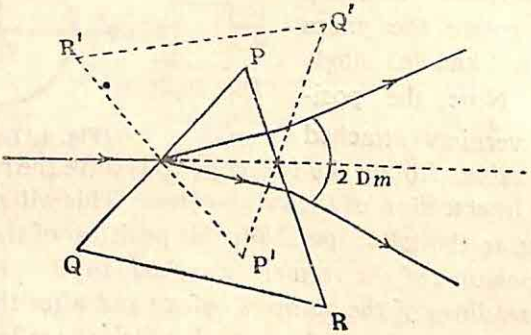
No. of obser-vations	Rotation of the reflecting susface (θ) in degrees	Position of the telescope		Rotation of the reflected ray in degrees (φ)			Ratio of φ and θ
		1st vernier	2nd vernier	1st vernier	2nd vernier	Mean	
1	10°			...			
2	20°.			(2)−(1)...			
3				(3)−(1)...			
...				(4)−(1)...			
...				(5)−(1)...			
6				(6)−(1)...			

Plot a graph with θ on x-axis, and θ on y-axis. This should give a straight line of slope 2, to prove that if the reflecting surface is rotated by θ, the reflected ray is rotated by 2θ.

Experiment 8. **To determine the angle of minimum deviation for a prism, and hence to determine its refractive index.**

Apparatus. Prism, spectrometer, sodium vapour lamp or sodium flame of Bunsen burner, spirit level, and electric bulb.

Theory. Keeping the direction of the incident ray fixed, the angle of incident of the ray over a face of the prism may be varied by rotating the prism about an axis passing through the centre of its base. As the angle of incidence gradually increases from its lowest value, the angle of deviation would decrease from its highest value so that the emergent ray moves in a direction away from the face of the prism.



(Fig. 4.18)

After the deviation of the emergent ray becomes minimum, the angle of deviation would start increasing if the angle of incidence is further increased by rotaing the prism in the same sense. The emergent ray, therefore, start moving in the opposite sense. Thus the position from where the emergent ray just starts moving in opposite direction, is the position of minimum deviation of the prism.

The direction of the incident ray remaining fixed, the prism may be rotated to shift the emergent ray on the other side of the incident rays as shown in the figure given above. In this condition also the prism may be put into the position of minimum deviation. The angle between the emergent rays in the two minimum deviation positions thus obtained by rotating the prism is equal to twice the angle of minimum deviation for the prism.

Further if D_m = angle of minimum deviation,

A = angle of the prism,

the refractive index μ of the material of the prism will be given by

$$\mu=\frac{\sin\frac{A+D_m}{2}}{\sin A/2}.$$

Procedure. (i) Adjust the spectrometer following the procedure of adjustments described in Expt. 6, and first obtain the angle of the prism by the method described in Expt. 7A or 7B.

(ii) Place the prism with the centre of its base over the centre of the prism table. Let one face of the prism receive the incident beam and try to see with naked eye the refracted image of the slit from the other face of the prism. Now rotate the prism from that position when the angle of incidence for the incident rays is quite small pursuing the image as it moves. After the prism comes to the position of minimum deviation, the image would start moving in opposite direction. Bring the telescope to receive the image and by clamping the prism table use the tangent screw attached to it to rotate the prism table to put the prism in the position of minimum deviation. Now bring the intersection of the cross-wires of the telescope over the image of the slit seen through it. Clamp the telescope and read its position by the two verniers attached to the prism table.

(iii) Now detach the vernier from the prism table and then clamp it so that it does not move with the prism table. Rotate the prism table to throw the emergent beam to the other side of the incident beam, and set it to the position of minimum deviation by the method described above. Move the telescope to bring the intersection of the cross-wires over the image of the slit, and read its position by the two verniers.

(iv) Find the difference between the vernier readings in the two positions of the telescope. This will give the value of twice the angle of minimum deviation. From this find the value of the angle of minimum deviation. Repeat the determination at least three times and find their mean.

Observations

Value of 1 small main scale division = ...

Least count = ...

(A to be determined as explained in Expt. 7B.)

Determination of D_m—

No. of observation	1st position of Telescope		2nd position of Telescope		Differences		Mean $2D_m$
	1st vernier	2nd vernier	1st vernier	2nd vernier	1st vernier	2nd vernier	
1	15°47′	183°50′	94°45′	262°40′	78°58′	78°50′	78°57′
2	15°52′	183°40′	94°44′	262°40′	78°52′	79°00′	
3	15°44′	183°40′	94°46′	262°40′	79°02′	79°00′	

Results. Mean value of $D_m = 39°28'{\cdot}5$.

Value of the angle of the prism $= A = 60°$.

$$\mu = \frac{\sin\dfrac{A+D_m}{2}}{\sin A/2} = \frac{\sin 49°44{\cdot}25'}{\sin 30°} = \frac{0{\cdot}7631}{0{\cdot}5000} = 1{\cdot}526.$$

Note. The value of μ of the prism depends upon the wave-length of the light used, and the value obtained by this experiment will be for the sodium yellow light, having mean wave-length $= 5893 \times 10^{-8}$ cm $= 5893 \times 10^{-10}$ m or 5893 A°.

EXPERIMENT 9. **To determine the refractive index of a liquid using a hollow prism.**

Apparatus. Hollow prism, spectrometer, sodium vapour lamp or sodium flame of Bunsen burner, spirit level, and electric bulb.

Theory. As in Expt. 8.

Procedure. (i) The angle A of the hollow prism is first of all measured by the method described in Expt. 7B. (ii) The prism is then filled with the experimental liquid, and the angle of minimum deviation D_m of the prism is then determined by the method described in Expt. 8. The temperature of the liquid is noted by a thermometer, and then the refractive index of the liquid should be calculated by the relation

$$\mu = \frac{\sin\dfrac{A+D_m}{2}}{\sin A/2}.$$

Observations

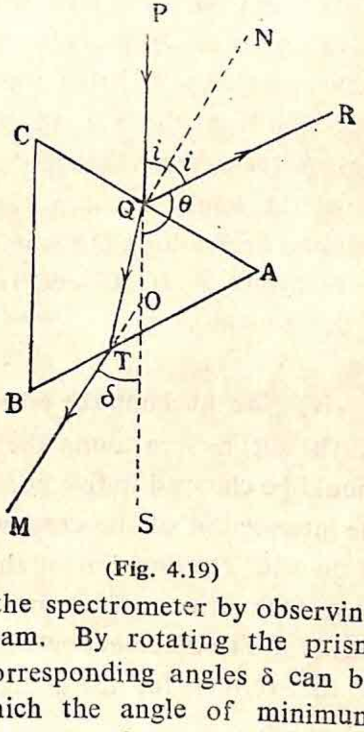
As in Expt. 7B and 8.

Result. Calculation as in Expts. 7B and 8.

EXPERIMENT 10. **To obtain the $i-\delta$ curve of a prism with the help of a spectrometer, and to determine the angle of minimum deviation from the curve.**

Apparatus. Same as for Expt. No. 8.

Theory. The ray PQ incident on the face AC of a prism emerges as the ray TM through the face AB of the prism after refraction through the prism. The angle between the direct ray and emergent ray is $\angle SOM = \delta$, which is called angle of deviation of the incident ray. If QN be the normal at the point of incidence, the angle of incidence corresponding to the angle of deviation of δ is $\angle PQN = i$. The reflected ray corresponding to the incident ray PQ is QR. Hence the $\angle PQR = 2i$. The angle $\angle SQR = \theta$, the angle between the direct ray and the reflected ray can be measured by spectrometer, and from this we will get, $i = \frac{1}{2}\ (180° - \angle SQR)$. The angle $\delta = SOM$ can also be measured by the spectrometer by observing the direct beam and the emergent beam. By rotating the prism i can be changed. The angles i, and corresponding angles δ can be measured, and $i-\delta$ plotted from which the angle of minimum deviation D_m may be determined. Further, if the angle A of the prism is known, the refractive index μ of the material of the prism can be calculated from the relation,



(Fig. 4.19)

$$\mu = \frac{\sin\dfrac{A+D_m}{2}}{\sin A/2}.$$

Procedure. (i) Adjust the spectrometer following the procedure of adjustments described in Expt. 6.

(ii) Without placing the prism on the prism table, obtain the direct image of the slit in the telescope. Clamp the telescope and move the tangent screw to bring the intersection of the cross-wires on the image. Read the positions of the verniers attached to the prism table. These provide readings for the direct beam position.

(iii) Rotate the telescope by 60° from its direct position, and clamp it there. Now place the prism on the prism table with the centre of its base over the centre of the prism table, its refracting edge A being on the axis of the collimator. Detach the verniers from the prism table and clamp it. Bring the reflected image of the slit, formed by reflection from the face AC of the prism, on the intersection of the crossewires as seen through the telescope by rotating the prism table. Now the angle between the direct beam along PS and the reflected beam along QR is set to 60°. This corresponds to the angle of incidence, $i=\frac{1}{2}(180^\circ-60^\circ)=60^\circ$. The prism should be clamped in this position.

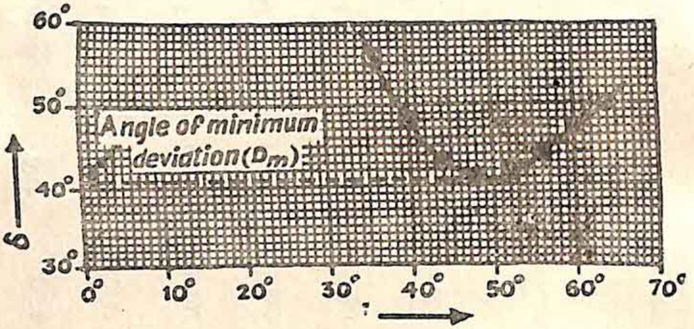
(iv) Now unclamp the telescope and rotate it to receive the image of the slit as seen along the emergent beam (TM). The telescope should be clamped in this position and by adjusting the tangent screw, the intersection of the cross-wires should be brought over the image of the slit. The position of the telescope may now be read with respect to the verniers. These provide the readings for the emergent beam position. The difference between these and the corresponding readings of the verniers for the direct beam position will give the angle of deviation.

(v) The prism table may be gradually rotated to change the angle of incidence in steps of 5°, and for every angle of incidence, the angle of deviation may be determined by the method described above. Angle of incidence should not be made less than 30°.

Observations

No. of observations	Position of direct beam (1)		Position of reflected beam (2)		Position of emergent beam (3)		Difference between (1) and (2)		$i=\frac{1}{2}(180°-\theta)$	Difference between (1) and (3)		
	Vernier I	Vernier II	Vernier I	Vernier II	Vernier I	Vernier II	Vernier I	Vernier II		Vern. I	Vern. II	Mean=δ
1	75°18′	255°8′	127°18′	307°8′	125°36′	305°00′	52°00′	52°00′	64°00′	50°36′	49°52′	50°14′
2	80°5′	260°5′	140°5′	320°15′	127°11′	307°15′	60°00′	60°00′	60°00′	47°06′	47° 0′	47°03′
3	100°10′	280°00′	168°10′	348°00′	144°15′	325°55′	68°00′	68°00′	56°00′	44°05′	43°55′	44°00′
4	120°04′	300°00′	196°04′	16°00′	160°34′	341°18′	76°00′	76°00′	52°00′	41°30′	41°18′	41°29′
5	65°10′	245°02′	149°10′	329°02′	106°34′	26°18′	84°00′	84°00′	48°00′	41°24′	41°16′	41°20′
6	70°03′	250°00′	162°03′	342°00′	113°03′	33°00′	92°00′	92°00′	44°00′	43°00′	43°00′	43°00′
7	80°00′	249°50′	180°00′	359°50′	128°06′	48°04′	100°00′	100°00′	40°00′	48°06′	48°14′	48°10′

Graph. With i on x-axis and δ on y-axis draw a graph. The graph will be of parabolic nature. Draw a straight line parallel to the x-axis from the minimum position of the graph. The point where this line cuts the y-axis gives the value of D_m, the angle of minimum deviation.



(Fig. 4.20)

Calculations and Results.

D_m from the graph = ..., Angle of the prism = ...

$$\mu = \frac{\sin\frac{A+D_m}{2}}{\sin A/2} = \ldots\ldots\ldots$$

EXPERIMENT 11. **To calibrate a prism spectrometer using *Hg* lines.**

Apparatus. Prism, spectrometer, sodium flame or sodium vapour lamp, spirit level, electric bulb, mercury discharge tube, and high voltage source for running the discharge tube.

Theory. The wavelength of the sodium yellow line is nearly midway between the extreme wavelengths of the visible radiation. Hence if a prism is set in the position of minimum deviation for sodium light, it is nearly so for other wavelengths of the visible radiation. Hence, for a prism set in the position of minimum deviation for sodium light deviations of light of various wavelength produced by the prism can be measured and wavelength, λ and diviation, δ graph will be the calibration curve of the prism spectrometer.

Procedure. (i) Adjust the spectrometer following the procedure of adjustments described in Expts 6 and 8.

(ii) Rotate the prism table so that the sodium light falls on one of the polished faces of the prism and see the image of the collimater slit through the other face. Rotate the table further until the image starts moving in opposite direction. Receive the image in the telescope. Clamp the prism table and work on the tangent screw attached to the prism table to bring the prism to the position of minimum deviation. Bring the intersection of the cross-wires of the telescope over the image of the slit. Clamp the telescope and read its position by the two verniers attached to the prism table. These readings represent the position of the deviated sodium light of mean wavelength 5893 A°.

(iii) Replace the sodium light by mercury discharge light and keeping the position of the prism unchanged determine the position of the deviated light for every spectral line observed following the procedure as adopted for sodium light. Also note the colours of the spectral lines.

(iv) Remove the prism from the prism table and unclamping the telescope rotate it to receive the direct light from the slit of the callimator. Bring the intersection of the cross-wire of the telescope over the image of the slit. Clamp the telescope and read its position by the two verniers attached to the prism table. These readings represent the position of the direct light.

(v) From the difference between the positions of the deviated and direct light determine δ for lights corresponding to each spectral line.

(vi) Use a standard spectral wavelength table for wavelengths of Hg lines, and plot λ − δ graph.

Observations

Value of 1 small main scale division = ... 20′
Least count = ... $\frac{1}{2}'$
Deviation δ :—

No. of obs.	Colour of the Spectral line	Wave-length (λ)	Position of the deviated light		Position of the direct light		Difference		Mean dev. (δ)
			Vernier I	Vernier II	Vernier I	Vernier II	Vernier I	Vernier II	
1	Sodium Yellow	5893 A° 5896 A°	143°43′ ...	323°43′	191°40′	371°42′			47°57′
2	*Hg* Orange	6192 A°	...						
3	,, Yellow	5780 A°	143°30′	323°40′			48°10′	48°2′	48°06′
4	,, Green	5461 A°	143°15′	323°13′			48°25′	48°29′	48°27′
	,, GB	4960 A°	142°27′	322°29′			49°13′	49°13′	49°13′
5	,, Blue	4358 A°	141°20′	321°22′			50°20′	50°20′	50°20′
6	,, Violet	4023 A°	140°30′	320°30′			51°12′	51°12′	51°12′

Results. The $\lambda-\delta$ graph is a curve showing decreasing δ with increasing λ. This is the calibration curve of the spectrometer which may be used to determine the wavelengths of the spectral lines of other sources.

Note. (i) Unless the spectro-meter has a high resolution, the two sodium yellow lines and *Hg* orange and yellow doublets will not be resolved. In such a situation only one sodium yellow line, and five *Hg* lines will be visible. It is also likely that due to poor intensity, *Hg* and orange line due to less sensitiveness to vision, *Hg* violet line may not be visible to eye. Hence only three or four *Hg* lines may be observed under ordinary conditions, and then the following mean wavelength for *Hg* lines may be used :

Orange→6192 A°, Yellow→5780 A°, Green→5461 A°,

Blue→4358 A°. Even orange line has not sufficient intensity.

(ii) A two feet mercury tube light may be used for the experiment if discharge tube is not available.

(iii) Time permitting, deviation (δ) may also be measured by observing the beam deviated on the other side of the direct light and a second $\lambda-\delta$ graph plotted.

EXPERIMENT. 12. To determine Cauchy's constants and the dispersion of the material of a prism.

Apparatus. As in Expt. 8, and a Helium discharge tube, a Rumkorff's induction coil with a storage cell or a high voltage transformer to run the Helium discharge tube.

Theory. All transparent substances absorb light selectively at certain wavelengths giving absorption bands in the spectrum. Between the consecutive absorption bands, but very far away from them, the refractive index of the substance varies with wavelength as per the Cauchy's equation $\mu=A+\frac{B}{\lambda^2}$, in a limited region of the spectrum. The dispersion of light in which μ decreases with λ as per the above equation, is termed as *normal dispersion* and A and B are the constants in the equation, called Cauchy's constants.

$\frac{d\mu}{d\lambda}=-\frac{2B}{\lambda 3}$ is referred to as the dispersion of the medium.

To determine the Cauchy's constant, one has to measure μ of the material by forming a prism. The measurement has to be done with lights of different λ. The μ is plotted against $\frac{1}{\lambda^2}$ giving a straight line, the slope of which gives B, the second Cauchy's constant. To get the first Cauchy's constant A, it will be convenient to make use of the various values of $\frac{B}{\lambda^2}$ by calculation using the above value of B and different values of λ. Bring the corresponding values of μ, a set of values for A should be calculated from the relation $A=\mu-\frac{B}{\lambda^2}$, from which the mean value of A be found out.

Dispersion $\frac{d\mu}{d\lambda}=-\frac{2B}{\lambda 3}$ is calculated for different values of λ using the value of B obtained. It is also determined from the slop of $\mu-\lambda$ dispersion curve for different values of λ.

Procedure. (i) Adjust the spectrometer following the procedure of adjustments as described in Expt. 6.

(ii) Determine the angle of the prism following the procedure as described in the Expt. 7 B.

(iii) Determine the angle of minimum deviation (D_m) by the prism using sodium light ($\lambda=5893$ A° $=5893\times10^{-10}$ m) following the procedure as described in Expt. 8.

(iv) Replace the sodium light by *He* discharge tube and connect its terminals to the output terminals of an induction coil or a high voltage transformer.

(v) Run the discharge tube by switching on the input of the induction coil or by connecting the input of the high voltage transformer to the 220 V main.

(vi) Adjust the position of the *He*-tube for obtaining maximum intensity of the spectral lines as seen through the telescope of the spectrometer.

(vii) Determine the angle of minimum deviation by the prism for every spectral line following the same procedure as for the sodium line.

(viii) Calculate the μ of the material of the prism for the sodium and *He* spectral lines using the measured respective values of D_m and the angle of the prism with the half of the expression

$$\mu=\frac{\sin\frac{A+D_m}{2}}{\sin A/2}.$$

Observations

Value of one small scale division = 20′.

Least count = $\frac{1}{2}'$ = 30″

1. Determination of A :— Table as in Expt. 7B.

2. Determination of D_m for lights of different wave lengths (*Na* and *He*-Spectral lines) :

No. of obs.	Colour of spectral line	Wavelength (λ)	1st position of Telescope		2nd position of Telescope		Difference (2 Dm)		Dm	μ
			1st Vernier	2nd Vernier	1st Vernier	2nd Vernier	1st Vernier	2nd Vernier		
1	*Na* Yellow	5893 Å	15°47′	183°50′	94°45′	262°58′	78°58′	78°50′	37°29′	1·526
2	*He* Red	6678 Å								
3	,, Yellow	5876 Å								
4	,, Green	5016 Å								
5	,, GB	4222 Å								
6	,, Blue I	4713 Å								
7	,, Blue II	4472 Å								
8	,, Violet	4026 Å								

3. $\mu - \frac{1}{\lambda^2}$ data :

No. of Obs.	λ in m	$1/\lambda^2 \times 10^{-9}$	μ
1	5893×10^{-10}	2879	1·526
2	6678×10^{-10}	2243	………
⋮			
8			

Results. Draw $\mu - \lambda \times 10^{-10}$ graph. Also draw $\mu - \frac{1}{\lambda^2} \times 10^{-19}$ graph will be a straight line of negative slope. Determine the slop of this st. line to obtain the second Cauchy's constant B. Use this value of B to calculate $\frac{B}{\lambda^2}$ and the dispersion, $\frac{d\mu}{d\lambda} = -\frac{2B}{\lambda^3}$. Also calculate $\frac{d\mu}{d\lambda}$ for different λ from $\mu - \lambda \times 10^{-10}$ graph by measuring slopes at different $\lambda \times 10^{-10}$.

Calculation of $\frac{B}{\lambda^2}$ and $\frac{B}{\lambda^3}$:—

No. of obs.	$\lambda \times 10^{-10}$	$\frac{1}{\lambda^2} \times 10^{-9}$	$\frac{B}{\lambda^2}$	$A = \mu - \frac{B}{\lambda^2}$	Mean A	Dispersion $= -\frac{2B}{\lambda^3}$	$\frac{d\mu}{d\lambda}$ by $\mu - \lambda \times 10^{-10}$ graph

Draw a graph of dispersion $\frac{d\mu}{d\lambda}$ against $\lambda \times 10^{-10}$. This will show a decrease in dispersion with increase of wavelength.

Value of the first cauchy's constant, $A = \ldots\ldots$

" second " " , $B = \ldots\ldots$

EXPERIMENT 13. To determine the number of lines per cm. of a plane diffraction grating and to use it to determine the wavelengths of the various components of the given light.

Apparatus. A spectrometer, a plane diffraction grating, a prism, spirit level, sodium flame of Bunsen burner, a helium tube, a Rumkorff's Induction coil or high voltage transformer, with a Storage cell.

Description : PLANE DIFFRACTION GRATING. In principle, a plane diffraction grating is a plate in which a large number of slits of equal width separated by opaque spaces of equal width are made. In practice, it consists of a plate of glass on which is pasted a piece of thin transparent *cellophane* paper ruled with a large number of equidistant lines of equal width. The lines are so close that they are not distinguishable by naked eye. The grating can be mounted on a stand called the grating stand and erected over the prism table of a spectrometer.

Theory. A plane diffraction grating arranged vertically over the prism table with its face normal to the beam of light of wavelength λ emerging from the collimator, will cause the diffraction of the beam and a number of primary maxima of different orders will be formed at the focal plane of the telescope. If θ be the angle of diffraction of the beam for the nth order primary maximum, and N be the number of lines per cm. of the grating, then

$$\sin\theta = Nn\lambda,$$

$$\text{or} \quad N = \frac{\sin\theta}{n\lambda}, \text{ and } \lambda = \frac{\sin\theta}{Nn}.$$

Hence if the source of light emits light of known wavelength, N can be known by determining the value of θ for a particular order of principal maximum.

After N has been determined, a source giving light of unknown wavelength may be taken, and after determining the value of θ for a principal maximum of a particular order for the light, the wavelength of the light may be calculated.

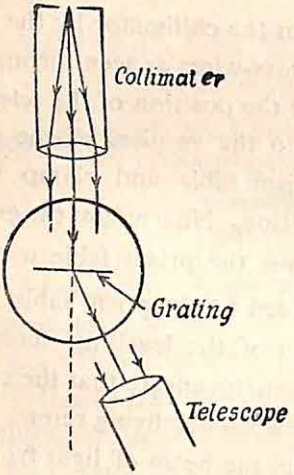
Procedure. (i) Adjust the spectrometer following the method of adjustments as described in Expt. no 6, using the sodium flame or sodium vapour lamp as the source.

(ii) Now receive the direct beam from the collimator by the telescope and bring the intersection of the cross-wires as seen through the telescope at the image of the slit. Read the position of the telescope on the scale attached to it with respect to the verniers of the prism table. Detach the verniers from the . prism table and clamp them. Move the telescope by 90° from this position. Now mount the grating on the grating stand and fix the stand over the prism table with the help of screws inside the holes provided on the prism table. The line joining these holes is parallel to two of the levelling screws of the prism table. Care should be taken to ensure that the central line of the grating is nearly midway between the fixing screws of the stand. Now rotate the prism table to let the beam of light from the collimator fall over the ruled surface. Receive the reflected image of the slit by naked eye and rotate the prism table to bring the image inside the telescope. If the centre of the image is not at the centre of the field of view, adjust the third screw of the prism table which is on the line perpendicular to the grating. The face of the grating then becomes normal.

(iii) Do not disturb the telescope. If necessary rotate the prism table to bring the reflected image exactly at the intersection of the crosswires. Note this position of the prism table by taking the vernier readings. Now unclamp the vernier and attach them to the prism table.

In this position the face of the grating makes an angle of 45° with the axis of the telescope. Now rotate the prism table by 135° from this position in the direction which moves the ruled surface of the grating away from the collimator and put it towards the telescope. Clamp the prism table in this position. This makes the surface of the grating normal to the incident beam.

(iv) Now unclamp the telescope and move it to receive the first order principal maximum, i.e., the first of the diffracted images



(Fig. 4.21)

of the slit. One of the two levelling screws that fall on the line parallel the grating surface should be adjusted a little to make the centre of the image coincide with the intersection of the cross-wires. As the first order principal maximum is also present on the other side of the direct beam, this adjustment is also to be repeated for the image on the other side of the direct beam. After a few adjustments on the two sides the direct beam, the lines of the grating become parallel to the slit (which is vertical). All adjustments are now complete and measurements may be made.

(v) Unless the source of light (sodium flame) is intense, make measurements with first order diffracted image only, for which $n=1$. Rotate the telescope to receive the first order diffracted image on the right hand side of the direct beam position. Clamp the telescope and move the tangent screw to bring the intersection of the cross-wires over the image. Note the position of the telescope on the scale attached to it by reading the verniers attached to the prism table.

(vi) Now unclamp the telescope and rotate it to receive the first order diffracted image of the left hand side of the direct beam position. Clamp the telescope and move the tangent screw to bring the intersection of the cross-wires over the image. Read this second position of the telescope. The difference between the first position and the second position of the telescope is equal to twice the angle of diffraction for the first order maximum.

(vii) After knowing the value of θ for the sodium light, calculate the value of N, taking the value of λ of sodium light to be 5893×10^{-8} cm.

(viii) Now erect the Helium tube vertically with the help of a wooden clamp and the central part of the tube in front of the slit of the spectrometer. Connect the terminals of the tube to the secondary of the Induction Coil or the output terminals of a high voltage source. Start the discharge of electricity through the Helium tube.

Light will be emitted due to the discharge of electricity through the gas.

(ix) Looking through the telescope a spectrum will be seen which will be quite intense in the first order. This will consist of lines of different colours. The angle of diffraction, θ for each of the lines should be separately determined by exactly the same method as has been described for the sodium line.

(x) After knowing θ for every line of helium light, the value of λ for each line in the order $n=1$ should be calculated.

Observations and Results

Value of one small main scale division = ..., LC = ...

Determination of N.

λ for sodium light = 5893×10^{-8} cm.

$n=1$

No. of obs.	1st position of Telescope		Second position of Telescope		2θ		
	1st Vernier	2nd Vernier	1st Vernier	2nd Vernier	1st Vernier	2nd Vernier	Mean
1	10°15′	190°22′	50°00′	230°07′	39°45′	39°45′	39°45′
2	10°14′	190°20′	49°55′	230°03′	39°41′	39°43′	39°42′
3	10°16′	190°23′	50°01′	230°08′	32°45′	39°45′	39°45′

Mean Value of $\theta = 19°52'$ and $\sin\theta = 0{\cdot}3398$

$$\therefore \quad N = \frac{\sin\theta}{\lambda} = 5766/\text{cm}.$$

Determination of λ of Helium light

$n=1$

Colour of the line	1st position of Telescope		2nd position of Telescope		2θ		Mean θ	Sin θ	λ in A°
	1st Vern.	2nd Vern.	1st Vern.	2nd Vern	1st Vern.	2nd Vern.			
Red	18°06′	199°13′	67°21′	247°30′	48°15′	48°17′	24°08′	0·4088	7089
,,	20°43′	200°50′	66°51′	246°32′	45°38′	45°48′	22°53′	0·3880	6726
Yellow	23°41′	203°48′	63°17′	243°24′	39°36′	39°36′	19°48′	0·3387	5872
Green	26°10′	206°18′	60°28′	240°40′	34°18′	34°22′	17°10′	0·2951	5116
Deep violet	28°18′	208°25′	58°25′	238°34′	30°09′	30°09′	15°04′	0·2599	4471

Notes. (i) The use of a lens before the collimator slit is advised in order to focus the light over the slit and increase the intensity of image seen by the telescope.

(ii) If the source is intense, the second order spectrum will be also visible through the telescope. In that case angles of diffraction for the lines in this order should also be determined and the values of λ calculated by using these values of the angles of diffraction. The accuracy in determination of λ in the second order will be better than that in the first order as the angles to be measured are larger so that they can be measured more accurately.

ASSOCIATED EXPERIMENT

1. To measure the wavelength difference between the sodium D_1 and D_2 lines.

Hints. Use a high power sodium vapour lamp to get the 2nd order grating spectrum. As in this case

$$n=2,\ \lambda_2-\lambda_1=d\lambda=\tfrac{1}{2},\ (\sin\theta_2-\sin{}_1).$$

EXPERIMENT 14. To determine the wavelength of sodium light by Newton's rings.

Apparatus. A convex lens, two plates of plane glass, a travelling microscope, a sodium flame, a wooden clamp with stand, and a thin convex lens of large focal length.

Theory. When a film of air of circular symmetry made by placing a thin convex lens of large focal length over a plate of plane glass is illuminated by a monochromatic light, interference of light reflected from the upper and the lower surfaces of the film takes place resulting in an interference pattern consisting of concentric bright and dark rings. These rings are called Newton's rings.

If R be the radius of curvature of the lower surface of the lens, then d_n, the diameter of the nth bright ring is given by

$d_n^2=2R(2n+1)\lambda$, where λ is the wavelength of the light.

Let the diameter of the $(n+s)$th bright ring be d_{n+s}, so that

$$d_{n+s}^2-d_n^2=4RS\lambda.$$

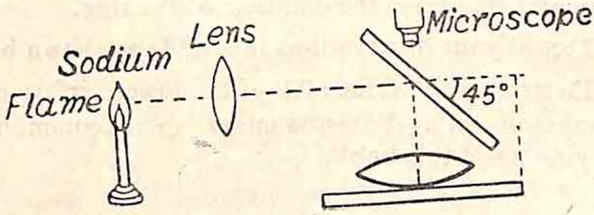
$$\therefore\quad \lambda=\frac{d_{n+s}^2-d_n^2}{4RS}.$$

Hence, if R is measured by a spherometer and d_{n+s} and d_n are measured with the help of a travelling microscope, λ can be calculated.

Procedure. (i) Make the platform of the microscope horizontal with the help of a spirit level.

(ii) Place a plane glass plate or slab on the platform of the microscope and the lens over the glass plate. Arrange the other glass plate into the clamp and bring it above the lens. Rotate the clamp to adjust the inclination of the plate to about 45° with respect to the plate placed below the lens.

(iii) Place a convex lens in front of the inclined plate, and arrange a sodium flame at nearly the focal plane of the lens. If the rays of light coming out of the lens are incident at an angle of 45° on the inclined glass plate, the reflected beam will fall vertically over the glass plate placed below the lens.



(Fig. 4.22)

(iv) Adjust the vertical height of the flame to be the same as that of the central part of the inclined plate. Make the axis of the microscope vertical and direct its objective towards the central part of the inclined plate. Now adjust the height of the microscope to see a system of bright and dark rings. In the event of difficulty in getting the rings, remove the lens from the plate and place a small piece of paper over the plate. Now move the microscope up or down, as may be necessary, to get a sharp image of the piece of paper. Now place the lens over the plate. A slight adjustment of the height of the microscope will bring the rings in the field of view. A slight adjustment of the inclination of the inclined plate may also be necessary to get the rings in the field of view.

(v) Now move slightly the plate placed over the platform of the microscope to bring the centre of the ring system over the intersection of the cross-wires as seen through the microscope. Rotate the eyepiece of the microscope to make one of the cross-wires perpendicular to the direction of horizontal motion of the microscope. Now move the microscope horizontally with the help of the screw attached to it to bring the cross-wires at the midpoint of the visible outermost bright ring. Next move the microscope in opposite direction and bring the cross-wire over the midpoint of that outer ring (say 20th ring) which is quite distinct. Note the position of the vernier on the horizontal scale. Moving the microscope in the same direction go on noting the position of the vernier as the cross-wire is placed at the midpoints of all the rings until the 5th or 4th ring from the centre is reached. Now move the microscope to the other side of the centre of the ring system. Moving the microscope in the same direction go on noting the positions of the vernier as the cross-wire is placed at the midpoints of the same rings as were observed on the other side of the centre until the outer-most ring (say 20th ring) is reached. The difference between the vernier readings on the two sides of a particular ring gives the diameter of the ring.

(vi) Record your observations in a table as shown below.

(vii) Determine the value of *R* of the lower surface of the lens by using a spherometer as discussed under some common experiments in the beginning of this book.

Observations

One small division of the horizontal main scale = ...

Least count = ...

Ring No. (*n*)	Readings of the Vernier		Diameter of the ring $=d$ Cm.	d_n^2	$d^2_{n+8}-d^2_n$
	Left side Cm.	Right side Cm.			
5	4·160	4·473	0·313	0·09796	$d_{13}^2-d_5^2 = \dots$ (*i*)
6	4·152	4·482	0·330	0·10892	$d_{14}^2-d_6^2 = \dots$ (*ii*)
7	4·143	4·491	0·348	0·12108	$d_{15}^2-d_7^2 = \dots$(*iii*)
8					$d_{16}^2-d_8^2 =$
9					$d_{17}^2-d_9^2 =$
...					$d_{18}^2-d_{10}^2 =$
...					$d_{19}^2-d_{11}^2 =$
20					$d_{20}^2-d_{12}^2 = \dots$(*viii*)

Mean of (i) to (viii) $d_{n+8}^2-d_n^2$ values.

$$= \dots$$

$$S = 8$$

Determination of R. For table and calculation see the General Physics section, for the determination of the radii of curvature of curved surfaces by a spherometer.

Calculations and Results. $\lambda=\frac{d^2{}_{n+8}-d_n{}^2}{4\times R\times 8}=\dots$

Plot a graph with d^2n against n. This will be a straight line.

Note. (i) In this experiment the choice of the radius of curvature of the lens used for making film of variable thickness is quite important. It is clear from the theory of the experiment that for the radii of the rings to be large the radii of curvature of the lens should be large. Hence it is advisable to use a lens of radii of curvature equal to 100 cm. in the experiment.

(ii) The thickness of the fringes at the centre of the fringes system is quite large. Hence the intersection point of the cross-wires cannot be accurately put at the midpoint of the width of these rings. Hence it is advisable to leave out first three to four rings during the observation.

ASSOCIATED EXPERIMENTS

1. Determination of the refractive index of a liquid by forming Newton's rings.

Hints. A few drops of liquid are placed over a plate of glass and a thin layer of liquid is made by putting a thin lens of large focal length. Making use of this layer Newton's rings are formed in the same way as Newton's rings are formed by making use of a film of air. The radii of the rings are determined in the same way as described in the main experiment, and then the mean value of $d'^2{}_{n+s}-d'^2{}_n$ is determined. If sodium light is used, then taking the value of λ to be 5893×10^{-8} cm, the refractive index of the liquid is determined from the relation

$$\mu=\frac{4RS\lambda}{d'^2{}_{n+s}-d'^2{}_n}.$$

If the wavelength of the light used is not known, then the experiment should be repeated with a film of air and the value of $d^2{}_{n+s}-d^2{}_n$ should be determined. Then using the expression

$$\mu=\frac{d^2{}_{n+s}-d^2{}_n}{d'^2{}_{n+s}-d'^2{}_n},$$

the refractive index of the liquid should be calculated.

2. Comparison of the radii of curvature of the surface of a convex lens by forming Newton's rings.

Hint. First all Newton's rings are formed by using one of the two surfaces to form an air film and then $d^2{}_{n+s}-d^2{}_n$ is determined. After that rings are formed by using the second surface to form another air film and then $d'^2{}_{n+s}-d'^2{}_n$ is determined. If R_1 and R_2 be the radii of curvature of the surfaces, then

$$\frac{R_1}{R_2}=\frac{d^2{}_{n+s}-d^2{}_n}{d_2{}'^2{}_{n+s}-d'^2{}_n}.$$

Hence $\frac{R_1}{R_2}$ can be calculated after determining $d'^2{}_{n+s}-d'^2{}_n$ and $d^2{}_{n+s}-d^2{}_n$.

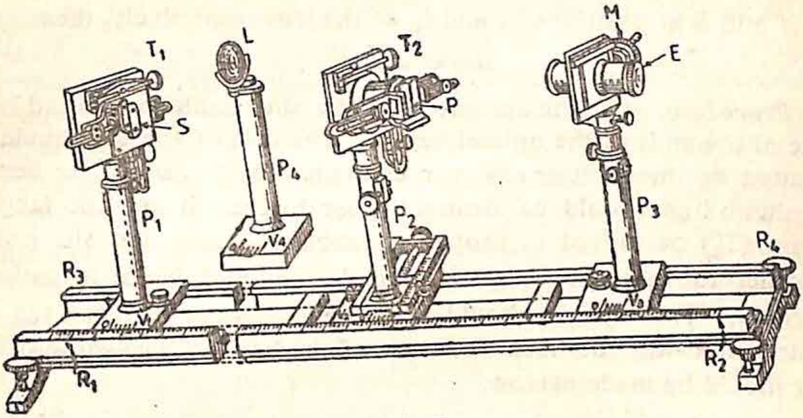
EXPERIMENT 15. To determine the wavelength of sodium light by a Bi-prism.

Apparatus. Bi-prism, optical bench with slit, Bi-prism, Micrometer eye-piece and their stands, sodium-vapour lamp, converging lens, a 100W electric bulb, index rod.

Description of Special Apparatus— (i) OPTICAL BENCH AND ITS ACCESSORIES. The optical bench has two horizontal rails (Fig. 4.23), one of these having a linear scale. The rails are accurately equidistant. These rails carry three uprights, the first carring an adjustible slit, the second carrying a mount for a bi-prism, and the third carrying a micrometer eyepiece. There uprights move smoothly over the rails with their verniers at their base moving over the main scale on a rail. The height of the slit (S) can be adjusted and it can be rotated by a tangent screw (T_1) to make it vertical. It can also be rotated about a vertical axis, and shifted side ways.

A Bi-prism can be placed in the mount carried by the second upright. The mount and hence Bi-prism can be rotated about a vertical axis. The Bi-prism can also be rotated about a horizontal axis which is parallel to rails of the optical bench, by a tangent screw (T_2). The height of the Bi-prism can also be adjusted. The Bi-prism can also be shifted perpendicularly to the bench by a screw drive attached at the base of the upright.

The third upright carries at its top a Ramsden eye-piece with a cross-wire. Its height can be adjusted and it can be rotated about a vertical axis. A micrometer screw is provided with the eye-piece for accurate measurement of its movement perpendicular to the bench.

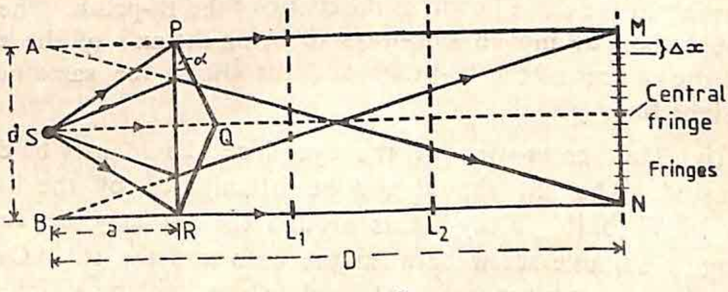


(Fig. 4.23)

An extra upright is also provided to arrange a converging lens between the eye-piece and the Bi-prism. The height of the lens over the upright can be adjusted and the lens can be rotated about a vertical axis.

(ii) **BI-PRISM**—It contains two accute angled prisms joined base to base, the accute angle being about $\frac{1}{2}°$ to $1°$.

Theory. The wavelength of light used in formation of fringes by a Bi-Prism is given by $\lambda = \triangle x . \frac{d}{D}$, where $\triangle x$ = separation between two consecutive fringes (fringe-width) of order n and $n+1$, D = distance between the eye-piece and the slit, and d = distance between the two virtual sources (A and B) as in fig. given below.



(Fig. 4.24)

d is obtained by focussing in the eye-piece the real images of the virtual coherent sources A and B with the help of a converging lens (of focal length f) at its two positions L_1 and L_2 (provided D is made greater than $4f$). If d_1 and d_2 are distances between the real images of A and B at positions L_1 and L_2 of the lens respectively, then

$$d=\sqrt{d_1 d_2}.$$

Procedure. (i) The upright with the slit should be shifted near one of the ends of the optical bench. The face of the slit should be rotated to make it nearly perpendicular to the rails of the bench. A plumb line should be arranged close to the slit and the tangent screw (T_1) be moved in proper direction to make the slit nearly parallel to the thread of the plumb line and hence to make it vertical. The upright should be moved side-way to bring the slit nearly mid-way between the rails of the bench. The width of the slit should be made narrow.

(ii) The Bi-prism should now be mounted on the second upright and this be pushed so that its base touches the base of the first upright carrying the slit. The height of the Bi-prism should be adjusted so that the centre of the Bi-prism and that of the slit are at the same height. The plane face of the Bi-prism should face the slit and it should be rotated about the vertical axis to make it nearly perpendicular to the rails of the bench. The obtuse edge N of the Bi-prism should be made nearly parallel to the slit by rotating it with the help of the tangent screw (T_2). Also the upright should be moved side-ways to bring this obtuse edge nearly mid-way between the rails of the bench.

(iii) The third upright should be pushed to bring it close to the second upright and the height of micrometer eye-piece over it should be adjusted so that the intersection of the cross-wire of the eye-piece is nearly at the same height as the centre of the Bi-prism. The upright should then be moved side-ways to bring the axis of the eye-piece and the centres of the Bi-prism and the slit in the same horizontal straight line.

(iv) The cross-wire of the eye-piece should now be distinctly focussed. The slit should now be illuminated by the light from the 100W bulb. Stray lights around the slit may be cut-off by using a suitable screw between the bulb and the slit. On seeing through the eye-piece some coloured fringes will be visible. These fringes should be made as distinct as possible by slow motion of the tangent screw with the Bi-prism attachment. The central fringe will be white.

(v) The central white fringe may not be formed over the intersection of the cross-wires of the eye-piece due to what is called *collimation error*, when the upright carrying the eye-piece pushed sufficiently away from the Bi-prism. This is because the beam coming out of the Bi-prism is not symmetrically spread on the two sides of the centre of the rails of the bench. In this position the bi-prism is moved side-ways untill the central white fringe falls over the intersection of the cross-wires. After this the upright is pushed quite near the Bi-prism and the micrometer screw is rotated to bring the intersection of the cross-wires over the central white fringe. The above two operations are successively repeated until it is found that the intersection of the cross-wires stays nearly over the central white fringe for both the positions of the eye-piece. Thus the collimation error is minimised.

(vi) The bulb is now replaced by the sodium-vapour lamp. The eye-piece upright is pushed away for that distance D from the slit at which the intensity of the fringe is good but the fringe width is too narrow.

(vii) Determine the pitch and L. C. of the micrometer scale. Start from one side of the fringe system. Move the eye-piece by turning the micrometer screw from that side. Put the intersection of the cross-wires at the centre of a bright fringe and take the micrometer reading. Call this fringe as the N^{th} fringe. Move micrometer screw to bring the intersection of the cross-wire over the $(N+5)^{th}$, $(N+10)^{th}$,........$(N+25)^{th}$ etc. fringes and go on noting the corresponding micrometer readings.

(viii) To measure d, mount a converging lens of such a focal length (f) that D is quite larger than $4f$, over the 4^{th} upright and place it between the Bi-prism and the eye-piece. Obtain sharply focussed images of the virtual sources in the eye-piece by adjusting the position of the lens at a suitable position (L_1). Measure the separation between the images (d_1) by moving the eye-piece side-way corresponding to one image position to another. Then shift the lens to the second suitable position (L_2) from where it again forms sharply focussed images of the virtual sources in the eye-piece. Measure the separation between these images (d_2) by moving the eye-piece side-way corresponding to one image position to another. Take three observations for both d_1 and d_2 and calculate d from their mean values.

(ix) To measure D_1 read the positions of the slit upright and the eye-piece upright from the scales at their base. Let the different between the positions of the two be D' cm. Now remove the Bi-prism and its upright, and place an index rod between the slit and the eye-piece horizontally. One end of the rod should be in contact with the slit while the other end should be focussed sharply by moving the eye-piece upright along the rails of the bench. The positions of the two uprights are then noted at their base scales. Let their difference be P. The length of the index rod (p) is then measured, and the index correction, x is calculated from $x = p - P$.

Now $$D = D' \pm x.$$

(x) Time permitting, the entire experiment may be repeated for three values of D.

Observations

Pitch of the micrometer scale $= 0{\cdot}05$ cm.

$$\text{L. C.} = \frac{0{\cdot}05}{50} = 0{\cdot}001 \text{ cm.}$$

$$D = 75{\cdot}3 - 0{\cdot}3 = 75{\cdot}0 \text{ cm.}$$

Measurement of the fringe-width $\triangle x$—

No. of obs.	Fringe No.	(MSR) Main Scale Reading in cm	(CR) Cap Reading	Cap R × L.C. in cm	Total in cm	Bracked Diff. in cm	Mean $\triangle x$ in cm
1	N	0·050	41	0·041	0·091		
2	N+5	0·200	24	0·024	0·204		
3	N+10	0·300	20	0·020	0·320	0·343	
4	N+15	0·400	34	0·034	0·434	0·343	0·02282
5	N+20	0·500	47	0·047	0·547	0·341	
6	N+25	0·650	11	0·011	0·661		
⋮							
10							

Measurement of d_1 and d_2—

d_1 or d_2	No of obs.	1st image				2nd image			
		M. S. R.	CR	CR×LC	Total in cm	MSR	CR	CR×LC	Total in cm
d_1	1	0·400	22	0·022	0·422	0·950	26	0·026	0·976
	2	0·400	22	0·022	0·422	0·950	26	0·026	0·976
	3	0·400	22	0·022	0·422	0·950	26	0·026	0·976
d_2	1	0·950	17	0·017	0·967	0·900	6	0·006	0·906
	2	0·950	17	0·017	·967	0·900	6	0·006	0·906
	3	0·950	17	0·017	0·967	0·900	6	0·006	0·906

d_1 in cm	d_2 in cm	$d=\sqrt{d_1 \times d_2}$ in cm
0·554 0·554 0·554 } 0·554	0·061 0·061 0·061 } 0·061	0·1847 cm.

Results. $\lambda = \triangle x . \dfrac{d}{D} = \dfrac{0{\cdot}2282 \times 0{\cdot}1847}{75}$

$= 5895 \times 10^{-8}$ cm $= 5895 \times 10^{-10}$ cm $= 5895$ Å.

Standard value of λ for sodium light = 5895 Å.

Notes. (i) To improve the intensity of illumination of the slit and hence the fringes, light may be concentrated over the slit by suitably placing a converging lens between the source and the slit.

(ii) By increasing the distance between the slit and the Bi-prism, the fringe-widths $\triangle x$ is decreased. This increase might become necessary so that the fringe-widths is not too wide and hence less intense.

(iii) Regional collimation error may be removed after the sodium light fringes have been obtained again by side-ways movements of the Bi-prism upright and the eye-piece by observing the movement of a fringe which is nearly centrally situated.

ASSOCIATED EXPERIMENT

1. To determine the angle of the Bi-prism by forming interference fringes.

Hints. If α be the acute angle of the Bi-prism. We have

$$d=2a(\mu-1)\alpha_1 \text{ and } \triangle x=\frac{D}{d}\lambda=\frac{D}{2a(\mu-1)\alpha}\lambda.$$

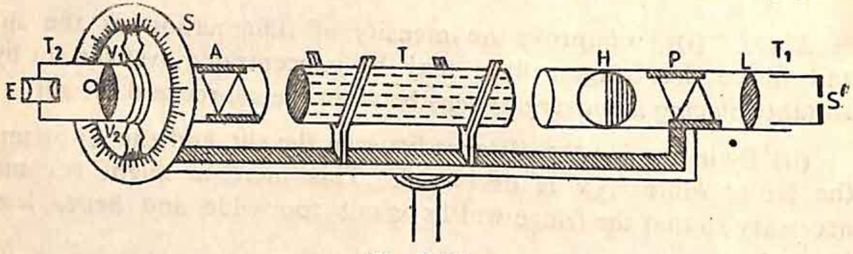
Take $\lambda=5893\times10^{-10}m$ for *Na* light used. Use $\mu=1{\cdot}54$ for glass and the measured value of $\triangle x$ to calculate α.

EXPERIMENT 16. **To determine the specific rotation of an optically active substance by a polarimeter.**

Apparatus. Half-shade polarimeter, sodium vapour lamp with a high voltage source, cane sugar, physical balance, measuring jar, and distilled water.

Description of Special Apparatus. HALF-SHADE POLARIMETER. The first tube (T_1) of the polarimeter has a slit (S'), a focussing lens (L) to render rays of light parallel, a polarising nicol (P), and a half-shade plate (H). This tube is fixed at one end of the polarimeter.

The second tube (T_2) of the polarimeter is fixed at its other end and contains an analysing nicol (A) and a telescope to receive the incoming light from the half-shade plate of the first tube. The analyser nicol is rotatable about the horizontal axis of the tube and its rotation can be observed on a circular scale (S) with Verniers (V_1 and V_2). On seeing the half shade through the telescope, its two halves appear to be of unequal brightness expect on the rotation of the analyser nicol there are two positions, mutually 180° apart, when the two halves are seen to be of equal brightness.



(Fig 4.25)

Between the two tubes (T_1 and T_2), is the third tube (T), arranged on a frame. It is this tube which contains distilled water or the experimental solution of the solute in solvent, usually distilled water. The two ends of this tube are closed by optically plane glass plates.

Theory. The C gms of optically active solute dissolved in 100 c.c. of solution made in an optically inactive solvent is the concentration or the strength of the solution. The amount $\frac{C}{100}=m$ gms is the solute per c.c. of the solution, and if a column of such a solution of length l cm or $\frac{l}{10}$ decimeter rotates the plane of polarisation of a plane polarised light by $\theta°$, then

$$\theta=S\frac{l}{10}m=S\frac{lC}{1000},$$

where S is the specific rotation for the solute defined as the rotation produced by a column of solution of one decimeter length containing one gm of active solute per c.c. of the solution

$$S=\frac{1000}{l}\cdot\frac{\theta}{C}.$$

Procedure. (i) Clean the tube (T) of the polarimeter with distilled water several times and then fill it up with distilled water and put it over the frame provided for it in the instrument. Ensure that there is no buble in the tube.

(ii) Illuminate the slit of the polarimeter by sodium light and see the two halves of the half-shade plate through the telescope. Rotate the analyser nicol until its two halves appear equally bright and note the readings of the positions of the two verniers. Repeat this adjustment and take observations three times.

(iii) Take out the tube and empty its content in a measuring jar. Note the volume v of the water. To prepare a 2% solution of the active substance. Calculate the amount w gms of the substance given by $w = \frac{2}{100}v$ gms. Take a clean and dry flask and weight it. Let it be M gms. Then introduce the substance in it, the amount of which should greater than w. Take the weight. Let it be $M+w'$. The volume v' of distilled water required for 2% solution is now calculated from

$$v' = \frac{100w'}{2} = 50w' \text{ c.c.}$$

Take this volume of distilled water in the measuring flask and transfer it into the flask containing the substance. Shake the flask to dissolve the substance. 2% solution is now ready. Note its temperature.

(iv) Put the solution in the dry tube of the polarimeter, and place it over the frame of the instrument. Ensure that there is no water buble in the solution. Rotate the analyser nicol while seeing the two halves of the half-shade plate. Find the position of the nicol at which the two halves of this plate appear equally bright and note the readings of the positions of the two verniers. Repeat this adjustment and take three observations.

(v) Repeat the experiment with 3% and 4% solutions.

(vi) Note the length of the tube (T) between the inner surfaces of its end plates three times.

Observations

Solute. Cane sugar.

Temperature of the solution = 26°·3C.

Length of the tube between the inner surfaces of its end plates

$$= \left.\begin{array}{l} 20{\cdot}3 \text{ cm} \\ 20{\cdot}2 \text{ ,,} \\ 20{\cdot}4 \text{ ,,} \end{array}\right\} 20{\cdot}3 \text{ cm} = l.$$

(i) *Preparation of Solution*

$$v = 61 \text{ c.c.}, \; w = 1{\cdot}25 \text{ gms.}$$

$$M = 32{\cdot}83 \text{ gms}, \; M + w' = 34{\cdot}54 \text{ gms;}$$

$$\therefore \; w' = 1{\cdot}71 \text{ gms and } v' = 85{\cdot}5 \text{ c.c. for } 2\% \text{ solution.}$$

(ii) *Data of Rotation* $L.C = 0^\circ\cdot 1$.

No. of obs.	Concentration of Solution (C)	Reading of rotation: M. S. R.	V. R.	VR×LC	Total	Mean	Rotation	Mean Rotation (θ)	$\frac{\theta}{c}$	Mean $\frac{\theta}{c}$
1	0%	28°	0	0°·0	28°·0					
2	(Distilled water)	29°	6	0°·6	29°·6	28°·53				
3		28°	0	0°·0	28°·0	(A)				
4		210°	0	0°·0	210°·0					
5		211°	2	0°·2	211°·2	210°·47				
6		210°	2	0°·2	210°·2	(C)				
1		26°	2	0°·2	26°·2					
2	2%	26°	0	0°·0	26°·0	26°·18	2°·35			
3		26°	3	0°·3	26°·3	(B)	(A)-(B)			
4		207°	8	0°·8	207°·8			2° 41	1°·21	
5		207°	4	0°·4	207°·4	208°·0	2°·47			
6		208°	8	0°·8	208°·8°	(D)	(C)-(D)			
	3%							3°·96	1°·32	1°·31
	4%							5°·60	1°·40	

Results. $S = \frac{1000}{l} \cdot \frac{\theta}{c} = \frac{1000}{20\cdot 3} . 1^\circ\cdot 31$

$= 64^\circ\cdot 5$ for $\lambda = 5893\text{Å}$, at $26^\circ\cdot 3$C

Standard value of S for cane sugar at 20°C and 4 to 8 percent concentration

$= 66^\circ\cdot 7$ for $\lambda = 5893\text{Å}$.

Plot a graph of θ against c.

ASSOCIATED EXPERIMENT

1. To determine the concentration of a cane sugar solution using a polarimeter (Saccharimetry)

Hints. Plot a rotation (θ) vers concentration (c) graph from the experimental data of θ for several known c of the cane sugar solution. Use now the solution of unknown concentration in the tube (T) and find the corresponding rotation (θ). From $\theta - c$ graph read c against this θ for the solution of unknown concentration.

EXPERIMENT 17. **To verify Brewsters' law.**

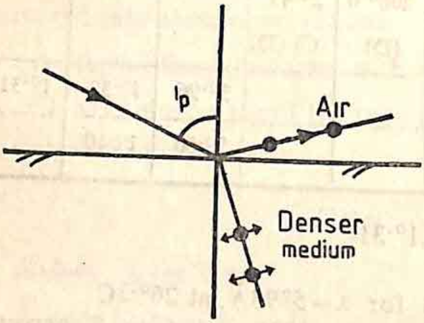
Apparatus. Spectrometer, analyser nicol in a mount, sodium vapour lamp, prism, spirit level.

Description of Special Apparatus. ANALYSER NICOL—This contains a nicol prism mounted in a hollow cylinder capable of being fitted in front of the objective of the telescope of a spectrometer. This can be rotated about the horizontal axis of the telescope and the rotation can be read over a circular scale backed by an indicator. If an unpolarised light is incident over the nicol, its rotation does not produce any change in the intensity of illumination in the field of view. If a partially polarised light is incident on the rotation of the nicol over a range of angle, one observes a minimum of illumination. But if a plane polarised light is incident one observes darkness in a narrow range of rotation of the nicol. The principal section of the nicol is then perpendicular to the plane of vibration of the plane polarised incident light.

Theory. For the given surface of a material that particular angle of incidence of unpolarised light at which the reflected light is plane polarised, is called the polarising angle (i_p) for the surface of the material (Fig. 4.26). The tangent of the polarising angle, i_p is equal to the refractive index, μ of the material i.e.

$$\tan i_p = \mu.$$

This is Brewster's Law.



(Fig 4.26)

Procedure. (i) Adjust the spectrometer following the procedure of adjustment described in expt. 6.

(ii) Measure the angle of the prism following the procedure of expt. 7B, and the angle of minimum deviation following the procedure of expt. 8. Calculate the μ of the material of the prism.

(iii) Remove the prism from the prism table and focuss the slit of the collimater directly by the telescope. Bring the image of the slit over the intersection of the cross-wires. Note the verniers to take reading of the position of the direct beam of light. Repeat this observation thrice and obtain the mean readings of the two verniers.

(iv) Now put the prism on the prism table with one of its polished faces just over the centre of the table. Also keep the centre of the face nearly above the centre of the table.

(v) Turn the telescope by 40° from it direct position and clamp it there. Rotate the prism table to bring the light reflected from the polarised face of the prism into the telescope. Clamp the prism table by turning the tangent screw attached to it. Bring the reflected image of the slit over the intersection of the cross-wires of the eyepiece of the telescope. The angle of incidence of light on the prism face is now 70°.

(vi) Fit up the analyser nicol-mount in front of the objective of the telescope. Rotate the analyser to find out the range φ_1 to φ_2 over its scale in which you observe the minimum of illumination of the image of the slit.

(vii) Turn the telescope away by intervals of 5°. Capture the reflected image in it and go on finding out the range one which you observe minimum of illumination of the image of the slit. Take observations up to an angle of incidence of 40°.

Observations

(i) *Angle of the Prism* (*A*)—Same table and calculation as in expt. 7B.

(ii) *Angle of Minimum Deviation* (D_m)—Same table and calculation as in expt. 8.

Calculate μ using the formula $\mu = \dfrac{\sin\frac{A+D_m}{2}}{\sin\frac{A}{2}}$.

Direct position of the beam—

No. of obs.	Reading of the first vernier	Mean	Reading of the second vernier	Mean
1				
2				
3				

Nicol prism readings at various angles of incidence—

No. of obs.	Angle of incidence (i)	Nicol prism reading			Inference about φ (wide or narrow)
		φ_1	φ_2	$\varphi=\varphi_1-\varphi_2$	
1	70°				
2					
3					
4					
5					
6					
7	40°				

Results. Plot a graph with the range of minimum illumination range, φ against the angle of incidence i_1 and from the graph determine the angle at which φ is minimum. This gives the polarising angle i_p.

Find tan i_p, and determine the difference between this and the value of μ as calculated from measurements of A and D_m.

It will be found that the relation $\tan i_p=\mu$ is correct within the limits of experimental error.

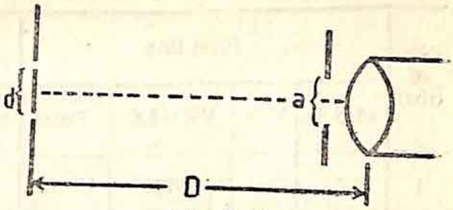
EXPERIMENT 18. To determine the resolving power of a telescope for various object distances and to test the validity of the expression for resolving power of a telescope.

Apparatus. Telescope, variable width slit, glass plate, measuring tape, travelling microscope.

Theory. If the source of monochromatic light is a pair of parallel bright lines then due to a single slit placed in front of the objective of a telescope, directed towards the lines, two diffraction patterns should be formed at the focal plane of the objective. When the width, a, of the slit is adjusted to such a value that the principal maxima of the two patterns, i.e. the images of the two bright lens, are just separated, then according to the Rayleigh's criterian for the limit of resolution, λ/a measures the angular separation θ of the bright lines for which their images are just resolved at the focal plane of the objective of the telescope. The reciprocal of λ/a is the resolving power.

If d be the separation between the two bright lines (sources) and D be distance between the telescope objective and either of the two lines

$$\theta = \frac{d}{D}.$$



(Fig. 4.27)

So that $$\frac{\lambda}{a} = \frac{d}{D}.$$

Procedure. (i) A pair of line sources may be made by fixing a black paper on a glass plate with gum and drawing two parallel lines over it with the edge of a sharp blade. The glass plate may be mounted vertically on a stand. The lines are illuminated a sodium vapour lamp from behind. The lines are made nearly vertical.

(ii) The telescope is errected on a vertical stand over a table and its height is adjusted to be nearly equal to the height of the middle part of the bright sources. The axis of the telescope is made horizontal and it is directed towards the sources.

(iii) Then the telescope is focussed to see the sharp and separated images of the line sources at the central part of its field of view.

(iv) The adjustible slit is errected vertically in front of the objective of the telescope as close to it as possible. Its width is gradually adjusted until the two images seen through the telescope just fail to be distinguished as separate images.

(v) Measure the width of the apperture with the help of a travelling microscope.

(vi) Repeat the experiment for several different distances (D) between the object and objective of the telescope (say, from 3 to 7 meters).

(vii) Measure the separation between the lines used as objects with the help of a travelling microscope.

Observations

1 main scale division of the travelling microscope

$= 0{\cdot}05$ cm.

L. C. $= 0{\cdot}001$ cm.

(i) Measurement of d—

No. of obs.	First line				Second line				
	M.S.R.	V.R	VR×LC	Total	M.S.R.	V.R.	VR×LC	Total	d in cm
1	9·55	20	0·020	9·570	9·25	46	0·046	9·296	0·274
2	9·55	20	0·020	9·570	9·25	45	0·045	9·295	0·275
3	9·55	21	0·021	9·571	9·25	44	0·044	9·294	0·277

Mean $d = 0·275$ cm.

(ii) Measurement of a at various D—

No. of obs.	D in cm	$d/D \times 10^{-5}$	Width of the slit (data)								Diff. $= a$ cm	$\frac{\lambda}{a} \times 10^{-5}$
			Initial (LHS)				Final (RHS)					
			M.S.R.	VR	VR×LC	Total	M.S R.	VR	VR×LC	Total		
1	300 cm	91·7	9·55	10	0·010	9·560	9·48	16	0·016	9·496	0·640	92·2
2	450 cm	61·1	9·65	30	0·030	9·680	9·55	30	0·030	9·580	0·100	58·9
3												
4												
5												

Results. It is found that the value of $\frac{\lambda}{a}$ approaches $\frac{d}{D}$. This verifies the expression for the resolving power of the Telescope.

Plot a graph with $\frac{\lambda}{a}$ against D, and draw your conclusion about variation of resolving power with object distance.

Notes. It is advisable to determine 'a' not only for the slit-width decreasing but also for the slit-width increasing in passing through the position of limiting state of resolution of the images. The average of the two observations will give a more accurate value of 'a'.

5. MAGNETISM

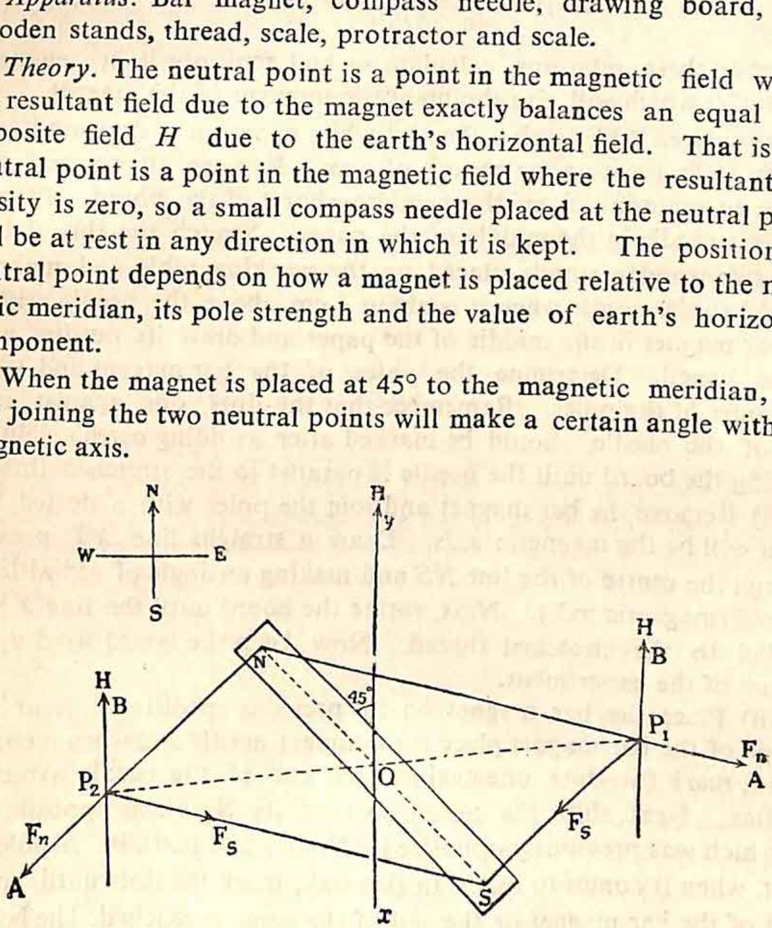
NEUTRAL POINT

Experiment 1. **Determination of magnetic moment of magnet by lines of force with magnet placed at 45° to the magnetic meridian.**

Apparatus. Bar magnet, compass needle, drawing board, two wooden stands, thread, scale, protractor and scale.

Theory. The neutral point is a point in the magnetic field where the resultant field due to the magnet exactly balances an equal and opposite field H due to the earth's horizontal field. That is, the neutral point is a point in the magnetic field where the resultant intensity is zero, so a small compass needle placed at the neutral point will be at rest in any direction in which it is kept. The position of neutral point depends on how a magnet is placed relative to the magnetic meridian, its pole strength and the value of earth's horizontal component.

When the magnet is placed at 45° to the magnetic meridian, the line joining the two neutral points will make a certain angle with the magnetic axis.



(Fig. 5.1)

If the component fields are denoted by F_n, F_s and H, we have

$$\frac{H}{\sin\angle SP_1A}=\frac{F_n}{\sin\angle SP_1B}=\frac{F_s}{\sin\angle BP_1A}$$

$$\therefore \quad F_n = \frac{\sin\angle SP_1B}{\sin\angle SP_1A}H \text{ and } F_s = \frac{\sin\angle BP_1A}{\sin\angle SP_1A}H.$$

But $F_n = \dfrac{m}{(NP_1)^2}$ and $F_s = \dfrac{m}{(SP_1)^2}$

where m = pole strength of the magnet.

$$\therefore \quad m = F_n.(NP_1)^2 = \frac{\sin\angle SP_1B}{\sin\angle SP_1A}(NP_1)^2.H \quad .. \quad (1)$$

and, $$m = F_s.(SP_1)^2 = \frac{\sin\angle BP_1A}{\sin\angle SP_1A}(SP_1)^2.H \quad .. \quad (2).$$

From these relations, calculate m and multiply it by magnetic length ($2l$) which will give the magnetic moment of the magnet.

Procedure. (i) Stretch a sheet of white paper on a drawing board and fix it in position by means of wax. Remove all magnets and magnetic materials from the neighbourhood of the board. Place a compass needle in the middle of the paper. Stretch the thread between two wooden stands placed on the working table and make it parallel to the needle when it is about 4 cm above the needle. Place the bar magnet in the middle of the paper and draw its outline with a fine pencil. Determine the poles of the bar magnet and write the names of the poles. Remember that the dots, one against each end of the needle, should be marked after avoiding earth's field by rotating the board until the needle is parallel to the stretched thread.

(ii) Remove the bar magnet and join the poles with a dotted line which will be the magnetic axis. Draw a straight line XY passing through the centre of the line NS and making an angle of 45° with the line NS (magnetic axis). Next, rotate the board until the line XY is parallel to the stretched thread. Now keep the board fixed up to the end of the experiment.

(iii) Place the bar magnet on its previous position. Near the N-pole of the bar magnet place the compass needle and when it comes to rest, mark two dots, one against each end of the needle avoiding parallax. Next shift the needle so that its S-pole is opposite the dot which was previously opposite its N-pole and mark its N-pole by a dot, when it comes to rest. In this way, mark the dots until some point of the bar magnet or the end of the paper is reached. The board should not be disturbed. Join the dots with a smooth curve. Indicate the direction of the line of force with an arrowhead. This curve will be the line of force in the combined fields of magnet and earth.

(iv) Putting the compass needle at different points near the N-pole of the bar magnet, draw a large number of lines of force. These lines of force should not be very close to or distant from each other. A curvilinear quadrilateral space will be formed.

(v) Narrow the region of curvilinear quadrilateral space by further drawing lines of force there. Place the needle in this small region and adjust its position carefully so that when disturbed by means of an iron-pin, it comes to rest in any position. Draw the outline of the compass needle and locate its centre which will give the neutral point, say, P_1.

(vi) Similarly locate the position of another neutral point P_2.

(vii) At P_1 and P_2, draw straight lines parallel to XY. Join N-P_1, N-P_2, S-P_1 and S-P_2 and measure them with a metre scale. Also measure NS with the scale which will give the magnetic length $2l$. Measure the angles SP_1B, SP_2B, SP_1A, SP_2A, BP_1A and BP_2A with a protractor in both the quadrants. Calculate m and M.

Observations and Calculations

Enter thus : $NS = 2l = \ldots.$ cm.,
$NP_1 = \ldots.$ cm., $NP_1^2 = \ldots.$ sq. cm.
$NP_2 = \ldots.$ cm., $NP_2^2 = \ldots.$ sq. cm.
$SP_1 = \ldots.$ cm., $SP_1^2 = \ldots.$ sq. cm.
$SP_2 = \ldots.$ cm., $SP_2^2 = \ldots.$ sq. cm.

	$\angle SP_1B$ in deg.	$\angle SP_2B$ in deg.	$\angle SP_1A$ in deg.	$\angle SP_2A$ in deg.	$\angle BP_1A$ in deg.	$\angle BP_2A$ in deg.
First quadrant						
Second quadrant						
Mean						

$\therefore$ $\sin \angle SP_1B = \ldots.$; $\sin \angle SP_2B = \ldots.$; $\sin \angle SP_1A = \ldots.$;
$\sin \angle SP_2A = \ldots.$; $\sin \angle BP_1A = \ldots.$; $\sin \angle BP_2A = \ldots.$
$H = \ldots.$ oersteds (supplied)

$$\therefore \text{ Pole-strength, } m = \left.\begin{array}{l}\text{(i) } \ldots. \text{ weber} \\ \text{(ii) } \ldots. \text{ ,,} \\ \text{(iii) } \ldots. \text{ ,,} \\ \text{(iv) } \ldots. \text{ ,,}\end{array}\right\} \text{Mean, } m = \ldots. \text{ weber}$$

$\therefore$ Magnetic moment, $M = m.2l = \ldots.$ weber-cm.

Result. Pole strength of the magnet = ... weber.

Magnetic moment of the magnet = ... weber-cm.

Precautions. (i) Before starting the experiment, all magnets and magnetic materials should be emoved from the neighbourhood of the board. (ii) At the time of determining the magnetic meridian, the bar magnet should be taken away to a safe distance from the board. (iii) While turning the board, it should not touch the wooden stands. (iv) The compass needle should be gently tapped before marking the dots opposite its two ends.

ASSOCIATED EXPERIMENTS

1. Place two bar magnets with their axes along a line and their *N*-poles facing each other at the given distance. Trace the lines of force, eliminating the effect of the earth's field, and compare their magnetic moments.

Hint. Trace the lines of force and hence locate the position of the neutral point. At the neutral point, the field due to one magnet is equal and opposite to the field due to the other magnet. Hence

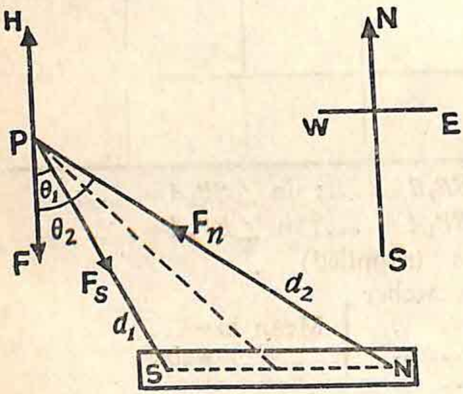
$$\frac{2M_1 d_1}{(d_1^2-l_1^2)^2}=\frac{2M_2 d_2}{(d_2^2-l_2^2)^2},$$

where d = the distance of the neutral point from the centre of the magnet.

$$\therefore \quad \frac{M_1}{M_2}=\frac{d_2}{d_1}\cdot\frac{(d_1^2-l_1^2)^2}{(d_2^2-l_2^2)^2}.$$

2. Place the given magnet at right angles to the magnetic meridian and locating the neutral points determine its magnetic moment (value of *H* will be supplied).

Hint. Trace the lines of force and locate the positions of neutral points. Here, at the neutral point *P* the resultant *F* of the forces F_n and F_s due to north and south poles of the bar magnet is equal and opposite to the horizontal component *H* of the earth's field. If the distances of neutral point *P* from north and south poles are d_1 and d_2 and the angles made by *SP* and *NP* with north-south line are θ_1 and θ_2, then $\frac{m}{d_1^2}\cos\theta_1-\frac{m}{d_2^2}\cos\theta_2=H$, where *m* is the pole strength of



(Fig. 5.2)

the bar magnet. Find out m from this relation.

Hence calculate the magnetic moment $M = m.2l$, where $2l$ is the distance between the two poles.

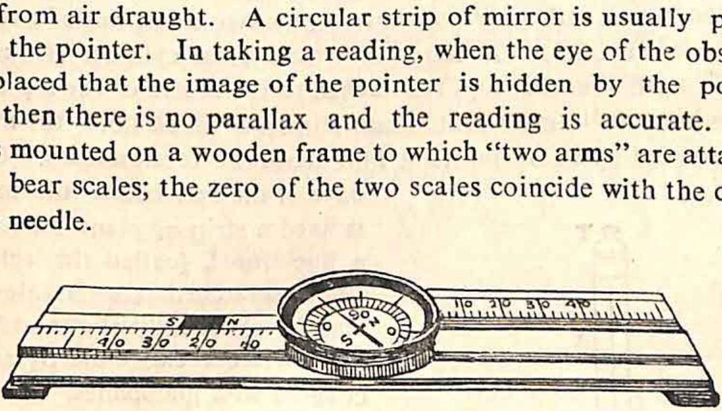
Note. Placing the bar magnet in any direction, this formula may be used.

MAGNETOMETERS

Experiment 2. **Determination of the absolute values of H and M by using deflection and oscillation magnetometers.**

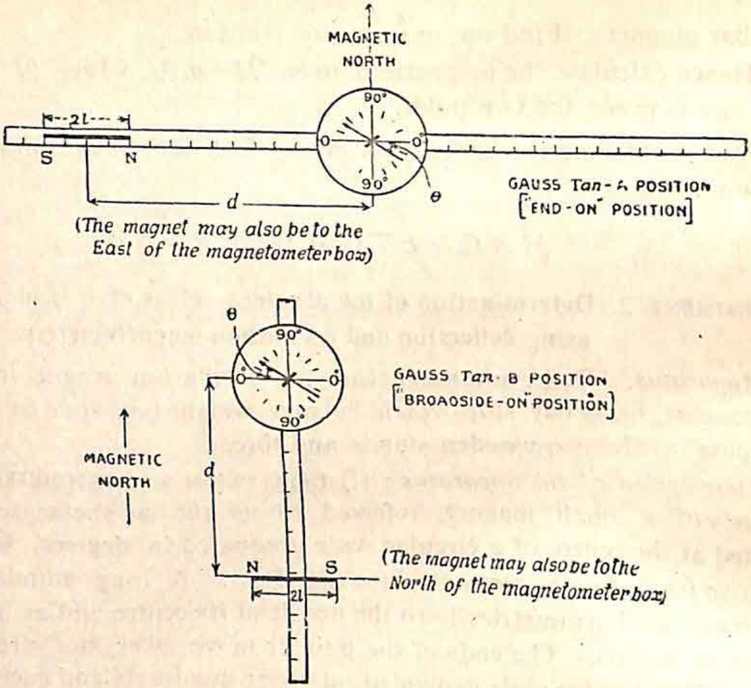
Apparatus. Deflection magnetometer, oscillation magnetometer, bar magnet, brass bar, stop-watch, balance, weight-box, slide callipers, compass needle, two wooden stands and thread.

Description of the apparatus : (i) DEFLECTION MAGNETOMETER : It consists of a small magnet, referred to as the magnetic needle, pivoted at the centre of a circular scale graduated in degrees, so as to move freely in a horizontal plane (fig. 5.3.). A long aluminium pointer is fixed symmetrically to the needle at its centre and at right angles to its axis. The ends of the pointer move over the circular scale. The circular scale is divided into four quadrants and each of them reads from 0° to 90°. The needle, pointer and scale are mounted in a glass-topped box (called magnetometer box) to protect them from air draught. A circular strip of mirror is usually placed below the pointer. In taking a reading, when the eye of the observer is so placed that the image of the pointer is hidden by the pointer itself, then there is no parallax and the reading is accurate. The box is mounted on a wooden frame to which "two arms" are attached which bear scales; the zero of the two scales coincide with the centre of the needle.



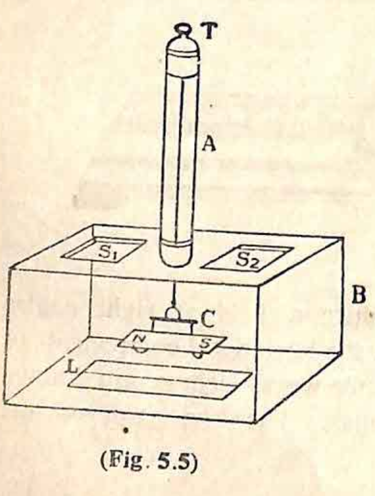
(Fig. 5.3)

The bar magnet can be used to produce a field at right angles to the magnetic meridian (along which the horizontal component of earth's field acts) in one of the two simple ways. These are known as Tan-A and Tan-B positions of Gauss. The two arrangements are shown in fig. 5.4.


MAGNETIC NORTH
90°
0
0°
90°
2l
S
N
d
θ
GAUSS Tan-A POSITION
["END-ON" POSITION]
(The magnet may also be to the East of the magnetometer box)
θ
90°
0
0
90°
GAUSS Tan-B POSITION
["BROADSIDE-ON" POSITION]
MAGNETIC NORTH
d
N
S
2l
(The magnet may also be to the North of the magnetometer box)

(Fig. 5.4)

(ii) OSCILLATION MAGNETOMETER : It consists of a rectangular wooden box B with glass windows on the two sides, one of which can be opened (fig. 5.5). A narrow vertical glass cylinder A having a torsion head V at the top, is attached to the centre of the top surface of the box. A brass or aluminium stirrup C which holds the magnet, is suspended by an unspun silk fibre from the torsion head. On the base of the box below the magnet, is fixed a strip of plane mirror with a fine line L (called the reference line) scratched on it along its length. Vertically above reference line there are two slots S_1 and S_2, covered with glasspanes, on the top surface of the box, through which the oscillations of the suspended magnet can be observed.



(Fig. 5.5)

Theory. If the deflection magnetometer is placed in the Tan-A position of Gauss, and the bar magnet produces a deflection θ on the magnetic needle, then

$$\frac{2Md}{(d^2-l^2)^2}=H\tan\theta$$

or

$$\frac{M}{H}=\frac{(d^2-l^2)^2}{2d}\tan\theta \qquad \dots \qquad (1),$$

where M = the magnetic moment of the bar magnet,
H = the horizontal component of the earth's field,
$2l$ = the magnetic length, and
d = the distance of the needle from the centre of the bar magnet.

If the same bar magnet is oscillated at the same place in an oscillation magnetometer, then the time period, T, of the bar magnet is given by

$$T=2\pi\sqrt{\frac{I}{MH}}$$

or

$$MH=\frac{4\pi^2 I}{T^2} \qquad \dots \qquad (2),$$

where I is the moment of inertia of the bar magnet about the axis of suspension. For a rectangular bar magnet,

$$I=w\left(\frac{a^2+b^2}{12}\right) \qquad \dots \qquad (3),$$

where w, a and b are the mass, geometrical length and breadth of the bar magnet respectively.

Dividing eqn. (2) by (1), we get,

$$H^2=\frac{4\pi^2 I}{T^2}\cdot\frac{2d}{(d^2-l^2)^2\tan\theta}$$

or

$$H=\frac{2\pi}{T(d^2-l^2)}\cdot\sqrt{\frac{2Id}{\tan\theta}} \qquad \dots \qquad (4),$$

Again, multiplying eqn. (2) by (1), we get,

$$M^2=\frac{4\pi^2 I}{T^2}\cdot\frac{(d^2-l^2)^2}{2d}\tan\theta$$

or

$$M=\frac{2\pi(d^2-l^2)}{T}\sqrt{\frac{I\tan\theta}{2d}} \qquad \dots \qquad (5).$$

Procedure. (i) Weigh the bar magnet (correct up to second place of decimal) and measure its length and breadth with slide callipers. Calculate the moment of inertia (I). Determine the magnetic length ($2l$) which is $\frac{5}{6}$ of the geometrical length. (This factor is not a constant but depends on the ratio of the geometrical length to the breadth of the magnet.)

(ii) Set the deflection magnetometer in Tan-A position of Gauss. For this purpose, stretch a thread between two wooden stands placed on the working table and make it parallel to the pointer. Now turn the arms of the magnetometer on the table until the arms are parallel to the stretched thread. Rotate the magnetometer box without disturbing the arms till the pointer reads 0°—0°. (If the magnetometer box is rigidly fixed in the wooden frame, usually the pointer reads 0°—0° when the arms are parallel to the stretched thread.)

(iii) (a) Place the bar magnet on one arm, say east arm, in such a way that its axis is parallel to the arms and when produced it passes through the centre of the magnetic needle. Adjust the distance of the centre of the magnet from the centre of the needle so as to get a deflection nearly 45° failing which between 25° and 65° at the same time keeping the value of d quite large. Avoiding parallax, read both ends of the pointer. Determine d, the distance of the needle from the centre of the bar magnet. It is the mean of the readings of the ends of the bar magnet.

(b) Turn the bar magnet upside down *in the same position* and read both the ends of the pointer.

(c) Keeping the bar magnet *at the same distance*, reverse the pole facing the needle and read both the ends of the pointer.

(d) Again turn the bar magnet upside down in the same position and read both ends of the pointer.

(e) Repeat the operations as above by placing the bar magnet on the *west arm at the same distance* as before. Find the mean of all the sixteen deflections which will give θ, free from errors.

(iv) Place a compass needle on the base of the *oscillation* magnetometer in such a way that its centre lies on the reference line. Rotate the magnetometer till the line is parallel to the needle. See the adjustment by viewing from the slot S_1 or S_2.

(v) Now place the brass bar of size and weight approximately equal to the bar magnet, on the stirrup in such a way that its upper face is horizontal and the axis of the rotation coincides with the vertical suspension fibre. The fibre, if twisted, will untwist itself. During the process of removal of twist, the motion of the brass bar should be checked after every few oscillations, otherwise when the fibre is untwisted, the inertia of the rotating bar may cause it to twist in the opposite direction. When the bar comes to rest, turn a little, if necessary, the torsion head so that the axis of the bar is parallel to the reference line. See the adjustment by viewing from the slot.

(vi) Now hold the stirrup tightly in position and withdraw the brass bar replacing it by the bar magnet used in the deflection experiment. The bar magnet should lie perfectly *horizontal* in the stirrup with its *north-pole* facing towards *north*

(vii) Next bring the N-pole of another magnet momentarily near the N-pole of the suspended magnet and set the latter into angular oscillations of small amplitude (nearly 4°). Take away the second magnet to a safe distance from the suspended magnet. Start the stop-watch exactly when one end of the bar magnet crosses the reference line from, say, left to right and count zero. When the same end of the magnet crosses the line from left to right, it has made one complete oscillation. When the magnet has completed 20 oscillations, stop the stop-watch. Repeat this process thrice and find the mean of the time taken in 20 oscillations. From this, find the time period (T) in sec. The oscillations should be watched through a slot from above.

Observations

Enter thus :

(A) Mass of the bar, $w = \ldots\ldots$gm.

(B) *Readings for geometrical length and breadth of the bar magnet.*

1 M. S. divn. of the slide callipers = ... cm.

....Vernier divisions coincide with....Main scale divisions

∴ 1 ver. divn. = ...cm.

∴ Least count of the slide callipers = ...cm.

Zero-error = ± ....cm. (If the zero-error is zero, state 'nil'.)

No. of obs.	Length, a in cm					Breadth, b in cm				
	M.S., in cm	Ver.	Total, in cm	Mean, in cm	Corrected mean, in cm	M. S., in cm	Ver.	Total, in cm	Mean, in cm	Corrected mean, in cm
1	...	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...	...

∴ Length of the magnet, $a = \ldots$cm.

Breadth of the magnet, $b = \ldots$cm.

(C) *Readings for the deflection*, θ.

Distance *d*, in cm	Arm used	Deflections, in degrees								Mean deflection θ in degrees	Tanθ
		N-pole towards needle				*S*-pole towards needle					
		Face up		Face down		Face up		Face down			
		End I	End II	End I	End II	End I	End II	End I	End II		
...	East	...	...	...	...	...	...	...	...	...	...
	West	...	...	...	...	...	...	...	...		

(D) *Readings for the time period*, *T*.

Time for 20 oscillations, in sec				Time period, *T* in sec
I	II	III	Mean	
...	...	...	...	...

Calculations.

$$I = w\frac{(a^2+b^2)}{12} = \ldots\text{gm-cm}^2$$

$$2l = \frac{5}{6}\times a = \ldots\text{cm.} \qquad \therefore\ l = \ldots\text{cm.}$$

$$H = \frac{2\pi}{T(d^2-l^2)}\sqrt{\frac{2Id}{\tan\theta}} = \ldots\text{oersteds.}$$

$$M = \frac{2\pi(d^2-l^2)}{T}\sqrt{\frac{I\tan\theta}{2d}} = \ldots\text{weber-cm.}$$

Result.

The horizontal component of the earth's field, $H = \ldots$oersteds.
The magnetic moment of the bar magnet, $M = \ldots$weber-cm.

Precautions. (i) Before starting, all magnets or magnetic materials should be removed from the neighbourhood of the magnetometers. (ii) To minimise the effect of friction at the pivot, the magnetometer box should be lightly tapped before taking the readings of the pointer. (iii) *The pivot of the needle may not pass exactly through the* *centre of the circular scale.* To correct for this error (called the 'eccentricity error') both the ends of the pointer should be read and the mean of the two readings should be taken. (iv) *The magnetic axis may not coincide with the geometric axis of the bar magnet.* To correct for this error, readings should be taken by turning the magnet upside down at the same position (v) *The magnetic poles of the bar magnet may not be equidistant from its geometric centre.* To correct for this error the readings should be taken by reversing the polarity of the bar magnet at the same position. (vi) *The centre of the circular scale may not coincide with the zero of the two scales of the two arms.* To correct for this error, readings should be taken by transferring the magnet on the other arm at the same distance. (vii) While taking the readings of the pointer, parallax error should be avoided. (viii) The deflection magnetometer should not be disturbed once it is properly set. (ix) There should not be any pendular oscillation of the suspended magnet in the oscillation magnetometer. If the suspended magnet executes unwanted motion, stop it by means of a light camel hair-brush. (x) The stirrup holding the magnet should be near the mirror fixed to the base, but should not touch it. (xi) As the moment of inertia of the stirrup has not been taken into account in the derivation of the above formula for T, it should be very light. It is better to have a loop of silk fibre for holding the magnet. (xii) The door of the box should be closed while noting time of complete oscillations.

Discussion. This method yields a satisfactory result. But it suffers from the following defects : The magnetic length cannot be determined accurately. As the magnetic needle is not sufficiently small, the field at the needle is not uniform. The friction at the pivot is not negligible. The 'pointer and the scale method' of measuring deflection is not susceptible to great accuracy. For greater accuracy the deflection should be about 45° and at the same time the distance d should be large.* The compliance with these two conditions at the same time is not always practicable. The amplitude is not sufficiently small. The moment of inertia of the stirrup is not sufficiently small. The fibre is not completely free from torsional reaction.

Note. For better result, a strong bar magnet should be used. Then both d and θ may be kept large. Further, the magnet may be regarded as swinging wholly in a uniform field of the earth.

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*d being large, an error in evaluating the magnetic length will not appreciably affect the final result. Further the larger the value of d the great is the uniformity of the field at the needle.

EXPERIMENT 3. Verification of the law of inverse squares of magnetism using Searle's magnetometer.

Apparatus. Searle's magnetometer, Robinson magnet, stop-watch, drawing board, compass needle, two wooden stands, thread, a wooden stand with clamps, metre scale and plumb line.

Description of the apparatus. (i) SEARLE'S MAGNETOMETER : It consists of a small cylindrical magnet about 15 mm in length and 1·5 mm in diameter, passing through the lower end of a heavy brass cylinder, which increases the moment of inertia of the system and hence the time-period (fig. 5.6). Below the magnetic needle is attached a long aluminium pointer (about 5 cm in length) to facilitate the counting of oscillations. The brass cylinder is suspended inside a glass cylindrical jar (about 30 cm in height and 6 cm in diameter) by means of an unspun silk fibre, the upper end of which passing through a hole in the centre of a circular card-board, which forms the upper lid of the jar, is tied to a brass pin. As the magnet is small, it may be regarded as swinging wholly in the uniform field.

(ii) ROBINSON MAGNET : It is a long ball-ended magnet. The poles are practically at the centres of the spheres (balls).

Theory. If the magnetic needle of magnetic moment M oscillates in the horizontal plane in the earth's horizontal field H, then its periodic time T_0 is given by,

$T_0=2\pi\sqrt{\frac{I}{MH}}=\frac{1}{n_0}$, where I = the moment of inertia of the suspended system,

or $H=\frac{4\pi^2 I}{M}n_0^2$ $\qquad n_0$ = the no. of vibrations per sec due to earth's field alone

or $H=Kn_0^2$ .. (1),

where $K=\frac{4\pi^2 I}{M}$ = a constant.

If now the ball-ended magnet is placed vertically with its N-pole at a distance d cm to the magnetic *south* of the magnetometer needle (and in the same horizontal plane as the latter), then since the effect of the S-pole is negligible, the field due to N-pole will assist the field due to earth so that the total field acting on the needle is equal to the sum of the two fields.

If the combined field of the earth and the magnet is $H+F_1$ and the time period T_1, then $H+F_1=Kn_1^2$, where $n_1=\frac{1}{T_1}$ = no. of vibrations per sec due to combined field of earth and magnet.

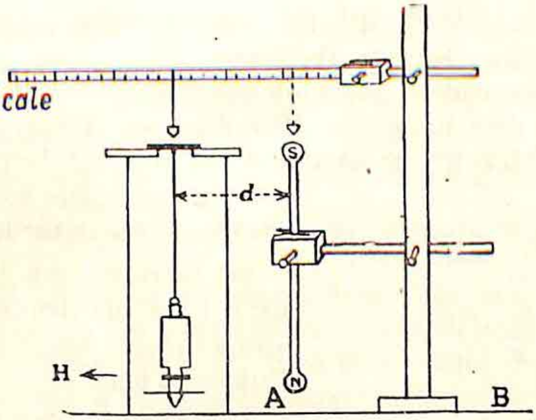
$$\therefore \quad F_1 = K(n_1^2 - n_0^2) \qquad \ldots \quad (2).$$

Similarly, $F_2 = K(n_2^2 - n_0^2)$, $F_3 = K(n_3^2 - n_0^2)$, etc.

If $F \propto \frac{1}{d^2}$, then $F_1 d_1^2 = F_2 d_2^2 = F_3 d_3^2 = \ldots . = \text{a constant}$

or $(n_1^2 - n_0^2)d_1^2 = (n_2^2 - n_0^2)d_2^2 = (n_3^2 - n_0^2)d_3^2 = \ldots . = \text{a constant.}$

Thus to verify the law of inverse squares it will be sufficient to show that $(n^2 - n_0^2)d^2$ is a constant or that a graph of $(n^2 - n_0^2)$ against $\frac{1}{d^2}$ is a straight line.



(Fig. 5.6)

Procedure. (i) Stretch a sheet of white paper on the drawing board and fix it in position by means of wax. In the middle of the paper draw a straight line *AB*. Remove all magnets and magnetic materials from the neighbourhood of the board and place a compass needle on the board. Stretch a thread between the two wooden stands and make it parallel to the needle. Next turn the board till the line *AB* is parallel to the thread, i.e., in the plane of the magnetic meridian. After this, do not disturb the board.

(ii) Place the magnetometer on the *northern* side of the line *AB* in such a way that the axis of the magnetometer needle and the line *AB* are in the same vertical plane. The lower end of the brass cylinder should remain a little above the bottom of the jar. Now oscillate the needle by bringing the *N*-pole of another weak magnet (or a rod of iron) momentarily near the *N*-pole of the needle. Take away the second magnet or rod to a safe distance from the needle. Observe the amplitude of oscillations. They should be equal on either side of the line. If not, there is torsion in the suspension. Then rotate the card-board carrying the pin in proper direction till the pointer oscillates equally on both the sides of the line AB.

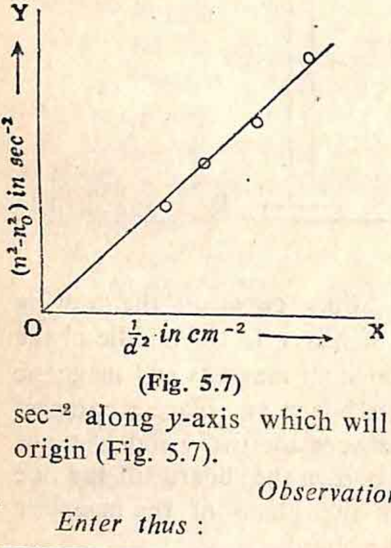
(iii) Again oscillate the needle with small amplitude (nearly 4°). There should not be any magnet or magnetic material in the neighbourhood of the magnetometer. Using a stop-watch, find the time taken for 30 oscillations Repeat this thrice and find the mean. Divide this mean by 30 which will give the time period (T_0).

(iv) Now clamp the ball-ended magnet in a wooden stand *vertically above the line AB* with its N-pole downwards and south of the magnetometer. Adjust the height so that the N-pole (centre of the lower sphere) is in level with the magnetometer needle. To start with, the distance between the centre of the needle and the N-pole of the Robinson magnet should be nearly 4 cm. Using stop-watch, find thrice the time taken for 30 osillations. Determine the time period (T_1). Measure the distance d_1 cm with the help of horizontally clamped metre scale and plumb line (as shown in the fig. 5.6).

(v) Increase the distance by about 1 cm and determine the time period (T_2). Also measure the distance d_2 cm.

(vi) Repeat operation (v) for five different distances.

(vii) Plot a graph taking $\frac{1}{d^2}$ in cm^{-2} along x-axis and $(n^2-n_0^2)$ in sec^{-2} along y-axis which will be a straight line passing through the origin (Fig. 5.7).



(Fig. 5.7)

Observations and Calculations

Enter thus :

No. of obs.	d in cm	$\frac{1}{d^2}$ in cm^{-2}	Time for 30 oscillations in sec				Time period in sec	$\frac{1}{T^2}=n^2$ in sec^{-2}	$(n^2-n_0^2)$ in sec^{-2}	$(n^2-n_0^2)d^2$
			I	II	III	Mean				
1	∞	0								
2	...		...	...	...	...	..(T_0)	...(n_0^2)	0	...
3	...		...	...	...	...	...(T_1)	...(n_1^2)	...	...
4	...		...	...	...	...	...(T_2)	...(n_2^2)	...	...
5	...		...	...	...	...	...(T_3)	...(n_3^2)	...	...
6	...		...	...	...	...	..(T_4)	..(n_4^2)	...	...
	...		...	...	...	...	...(T_5)	...(n_5^3)	...	...

Conclusion. (i) The value of $(n^2-n_0^2)d^2$ is very nearly constant, hence law of inverse squares is verified.

(ii) The graph of $(n^2-n_0^2)$ against $\frac{1}{d^2}$ is a straight line which also verifies the above law.

Precautions. (i) The lower N-pole should be on the same horizontal level as the magnetometer needle. (ii) The N-pole should be on the meridian line passing through the needle. (iii) The N-pole should be south of the magnetometer. (iv) The ball-ended magnet should be kept vertical. (v) Check that F_1 and H are additive by observing that T_1 is less than T_0.

Note. By placing the ball-ended magnet horizontally, the experiment can be performed. Remember that the N-pole of Robinson magnet should always point the north direction.

ASSOCIATED EXPERIMENTS

1. Find the magnetic length (or the magnetic moment) of a bar magnet.

Hint. Set the direction magnetometer in Tan-B position of Gauss. For this purpose, stretch a thread between two wooden stands placed on the working table and make it parallel to the magnetic needle. Now turn the arms of the magnetometer on the table until the arms are parallel to the stretched thread. Rotate the magnetometer box without disturbing the arms till the pointer reads $0°-0°$.

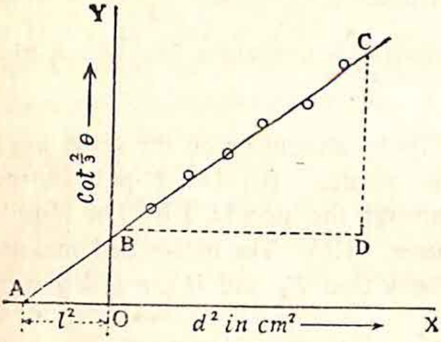
Place the bar magnet on one arm, say *north* arm, in a symmetrical position perpendicular to the arm. Avoiding parallax, read both ends of the pointer. Determine d, the distance of the centre of the needle from the centre of the bar magnet. Turn the bar magnet upside down in the same position and read both ends of the pointer. Reverse the bar magnet in position (end for end) and again read both ends of the pointer. Again turn the bar magnet upside down in the same position and read both ends of the pointer.

Repeat the operation as above by placing the bar magnet on the *south* arm at the same distance as before. Find the mean of all the sixteen deflections which will give θ, free from errors.

Repeat for different values of d over as wide a range as possible provided the deflection is between 25° and 65°.

For the "broadside-on" position, $M=(d^2+l^2)^{3/2}\,H\tan\theta$,

from which it can be seen that $d^2+l^2=\left(\frac{M}{H}\right)^{2/3}\cot^{2/3}\theta$.



(Fig. 5.8)

Hence on plotting $\cot^{2/3}\theta$, against d^2, a straight line graph is obtained. Thus by extrapolating the graph to $\cot\theta=0$, the intercept OA is obtained from which l can be determined. For, when $\cot\theta=0$, $d^2+l^2=0$, i.e. $d^2=-l^2$. Also, the slope $\left(=\frac{CD}{BD}\right)$ will give the value of $\left(\frac{H}{M}\right)^{2/3}$ from which M can be determined (provided the value of H is given).

Enter thus :

No. of observations	Distance d, in cm	Arm used	Deflections, in degrees								Mean deflec. θ, in degrees	$(\cot\theta)^{2/3}$	d^2, in cm²
			North pole towards east				South pole towards east						
			Face up		Face down		Face up		Face down				
			End I	End II	End I	End II	End I	End II	End I	End II			
1	...	North	..	..	..	..	..	..	..	..	..	..	..
		South	..	..	..	..	..	..	..	..			
2													
...													
...													
...													

By extrapolation, $OA=\ldots.$

$l=\sqrt{OA}=\ldots$cm.

Magnetic length $(2l)=\ldots.$cm.

From slope $\frac{CD}{BD}=\left(\frac{H}{M}\right)^{2/3}=\ldots.$

$H=\ldots.$oersteds (given)

$\therefore$ $M=\ldots.$weber-cm.

2. Verify the law of inverse squares of magnetism using a deflection magnetometer.

Hint. Set the deflection magnetometer in Tan-*A* position of Gauss. Obtain a series of values of the angle of deflection (θ_A) for a range of values of *d*.

Next set the deflection magnetometer in Tan-*B* position of Gauss. Again obtain the values of the angle of deflection (θ_B) for the same values of *d* as before. Deflection should lie between 25° and 65°.

Let θ_A and θ_B be the deflections observed for the same value of *d* in Tan-*A* and Tan-*B* positions of Gauss respectively.

In Tan-*A* position, $\frac{M}{H}=\frac{(d^2-l^2)^2}{2d}\tan\theta_A$, and

in Tan-*B* position, $\frac{M}{H}=(d^2+l^2)^{3/2}\tan\theta_B$.

Both these expressions are obtained on the assumption of the law of inverse squares. Consequently any relationship derived from them must in turn depend on the truth of the law.

$$\text{Now,}\quad \frac{\tan\theta_A}{\tan\theta_B}=\frac{2d(d^2+l^2)^{3/2}}{(d^2-l^2)^2}=\frac{2d^4\left(1+\frac{3}{2}\frac{l^2}{d^2}\right)}{d^4\left(1-2\frac{l^2}{d^2}\right)}$$

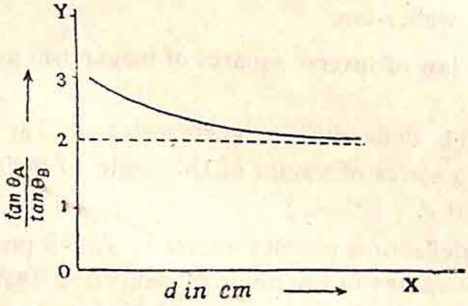
$$=2\left(1+\frac{3}{2}\frac{l^2}{d^2}\right)\left(1+2\frac{l^2}{d^2}\right)=2\left(1+\frac{7}{2}\frac{l^2}{d^2}\right)$$

$$=2+7\frac{l^2}{d^2}\ \text{(neglecting higher powers of } l/d).$$

For a short magnet,

$$\frac{\tan\theta_A}{\tan\theta_B}=2.$$

Thus if it can be shown that the above relationship holds good, then the law is verified. A graph of $\frac{\tan\theta_A}{\tan\theta_B}$ against *d* should show the ratio $\frac{\tan \theta_A}{\tan \theta_B}$ approach the line through 2 as $d \to \infty$, i.e , as the theoretical condition of l being negligible compared with d is realized.



(Fig. 5.9)

This method is called the Gauss's proof of the above law.

Note. (i) In the above proof, it is advised to take a magnet about 2 to 3 cm in length to ensure a good accuracy of results.

(ii) The law may be verified approximately by taking a bar magnet of 15 to 20 cm and utilising the tangent-A position of the deflection magnetometer. If the effect of the pole away from the magnetometer needle is ignored, then the field F at the centre of the needle due to the pole of the magnet facing the needle is given by

$F = H \tan \theta_A = \frac{m}{d^2}$, provided the inverse square law is true where m = pole strength of the magnet.

Hence, if it is shown that $d^2 H \tan \theta_A = m$ = a constant for different values of d and corresponding value of θ_A, then the law is established indirectly.

3. Using the two given bar magnets jointly, compare their magnetic moments by an oscillation magnetometer.

Hint. Place the two bar magnets together (one above the other) in the stirrup with their north poles pointing in north direction. Insert strips of paper between the magnets to avoid sticking. Find out the time period of oscillation in the usual way. Let this be T_1 (sec).

Take out one bar magner (the weaker*) and replace it in the stirrup with its axis reversed. Again determine the time period of oscillation. Let this be T_2 (sec). The magnets should be arranged symmetrically with parallel axes in the same vertical plane.

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*The weaker magnet can be found before the experiment by bringing the magnets in turn near to a compass needle—that having the smaller effect at the same distance is clearly the weaker.

The moment of inertia of the suspended system is not changed by reversing one of the bar magnets, but the magnetic moment of the system is in the first case equal to M_1+M_2 and in the second case M_1-M_2, M_2 being the magnetic moment of the weaker magnet. Thus,

$$T_1=2\pi\sqrt{\frac{I_1+I_2}{(M_1+M_2)\,H}}, \text{ and } T_2=2\pi\sqrt{\frac{I_1+I_2}{(M_1-M_2)\,H}}.$$

By squaring and dividing,

$$\frac{T_1^2}{T_2^2}=\frac{M_1-M_2}{M_1+M_2},$$

whence

$$\frac{M_1}{M_2}=\frac{T_1^2+T_2^2}{T_1^2-T_2^2}.$$

Without determining the moments of inertia of the two bar magnets, we can compare their magnetic moments by this method.

4. Determine the intensity of magnetisation of the given bar magnet using a deflection magnetometer. Value of H will be supplied.

Hint. Using deflection magnetometer in Tan-A position, calculate the magnetic moment, M, of the bar magnet. Also determine its volume by measuring its length, breadth and thickness with slide callipers. Then, intensity of magnetisation,

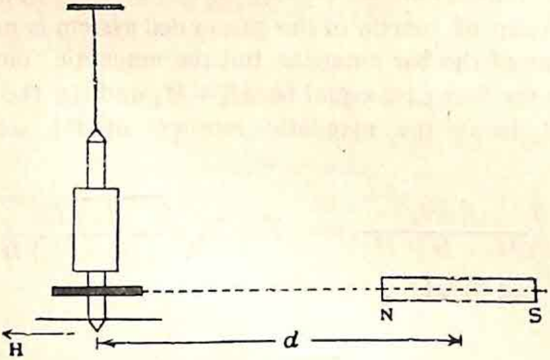
$$I=\frac{\text{Magnetic moment}}{\text{Volume}} \text{ C. G. S. unit.}$$

5. With the help of Searle's magnetometer find the magnetic moment of the given bar magnet. Value of H will be supplied.

Hint. Find the time period of oscillation in the earth's field alone. Let it be T_0 (sec).

Next place the given bar magnet with its centre at a distance of about 15 cm from the centre of the needle due south of it and its N-pole pointing north as shown in the figure below and find the time period of oscillation in the combined field of earth and the magnet. Let it be T_1 (sec). Measure the distance between the centre of the magnet and the centre of the needle. Let it be d_1 (cm). Repeat the experiment for three different distances, increasing the distance by about 2 cm each time.

Also measure the length of the bar magnet, from which calculate the magnetic length ($2l$).



(Fig. 5.10)

Then
$$T_0 = 2\pi\sqrt{\frac{I}{M_0 H}}$$

and
$$T_1 = 2\pi\sqrt{\frac{I}{M_0(H+F_1)}}$$

where I = moment of interia of the suspended system,
M_0 = magnetic moment of the needle,
H = horizontal component of the earth's field and
F_1 = the field due to the given magnet.

Hence,
$$\frac{T_0^2}{T_1^2} = \frac{H+F_1}{H}, \text{ or } \frac{F_1}{H} = \frac{T_0^2 - T_1^2}{T_1^2}.$$

But $F_1 = \frac{2Md_1}{(d_1^2 - l^2)^2}$, where M = magnetic moment of the given magnet.

$$\therefore \quad \frac{2Md_1}{H\,(d_1^2 - l^2)} = \frac{T_0^2 - T_1^2}{T_1^2}, \text{ or } M = \frac{H\,(d_1^2 - l^2)^2}{2d}\left(\frac{T_0^2 - T_1^2)}{T_1^2}\right).$$

Hence M can be calculated.

6. Show graphically the variation of magnetic field due to a bar magnet, along the prolongation of the axis of the given bar magnet.

Hint. Set the deflection magnetometer in tan-A position of Gauss. Obtain a series of values of the angle of deflection (θ) for a range of values of d.

Enter thus :

No. of obs.	Distance d (cm)	Mean θ	$\tan\theta$	H (Gauss)	$F=H\tan\theta$ (Gauss)
1	10	...	...		...
2	11	...	...	0·36	...
3	12	...	...		...
...	...	...	...		...
10	25	...	...		...

Now plot a graph taking d along x-axis and F along y-axis.

7. Show graphically the variation of magnetic field due to a bar magnet, along a line passing through its centre and perpendicular to its axis.

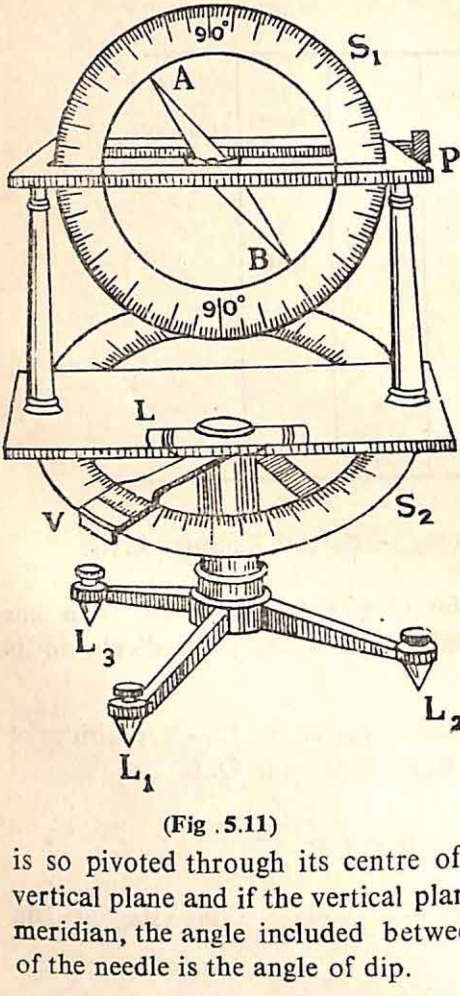
Hint. Set the deflection magnetometer in Tan-*B* position of Gauss. Enter your results and plot a graph as in Q. 6.

DIP CIRCLE

EXPERIMENT 4. Determination of the magnetic dip using a Dip circle.

Apparatus. Dip circle, two magnets, a wooden frame for use in remagnetising the dip needle, brass tweezers (or two finger gloves).

Description of the apparatus. DIP CIRCLE : It consists of a magnetic needle *AB* provided with a fine steel axle at its centre of gravity and at right angles to its length. The axle rests *horizontally* on two agate knife edges so that it may turn freely and with a minimum friction. The needle is free to rotate in the plane of the vertical circle S_1, which is graduated in degrees, 0° – 0° being on the horizontal line and 90° 90° on the vertical line. The axle passes through the centre of the circular scale S_1. The instrument has a *screw type lifter P* which can raise the needle off



(Fig .5.11)

the knife edges into two V-supports so that the axle of the needle coincides with the axis of the circle S_1. The whole system is contained in a wooden box with glass sides, mounted on a stand so that it can be rotated about a vertical axis. The angle of rotation is given by a vernier V moving over a horizontal circular scale S_2 graduated in degrees. The instrument rests on three levelling screws L_1, L_2, L_3 and the levelling can be tested by means of a spirit level L.

Theory. Dip at any place is the angle which the direction of the earth's total magnetic intensity makes with the horizontal line in the magnetic meridian at that place. Hence, if the magnetic needle is so pivoted through its centre of gravity as to move freely in a vertical plane and if the vertical plane coincides with the magnetic meridian, the angle included between the horizontal and the axis of the needle is the angle of dip.

Procedure. (i) Carefully level the instrument. Turn the screw P and lower the needle on to the knife-edges.

(ii) *Adjusting the plane of the dip circle in the magnetic meridian.*

(a) Rotate the upper part of the instrument until the needle appears to be vertical. Adjust until the top of the needle A is at the 90° mark. Read the zero of the vernier on the horizontal circular scale. The bottom of the needle may not be exactly at 90°. So rotate the upper part of the instrument until the bottom of the needle is at the 90° mark. Read the zero of the vernier on the horizontal scale.

Mark this face of the instrument and the needle with ink or chalk to indicate that this face is, say, towards the *south.*

(b) Next rotate the upper part of the instrument through 180°. The marked face of the instrument and that of the needle are now towards the north. Adjust until the top of the needle is at the 90° mark. Read the zero of the vernier on the horizontal scale. Again adjust until the bottom of the needle is at 90° and read the zero of the vernier on the horizontal scale.

(c) Reverse the needle on its bearings (using the brass tweezers or with fingers covered with gloves) and repeat the two readings. Now rotate through 180° and repeat the two readings. Here the face of the instrument is towards the south but the marked face of the needle is now towards the north.

(d) Find the average of the eight readings. If the horizontal scale is graduated from 0° to 360°, then set the upper part of the instrument exactly at the average reading. The vertical plane in which the needle moves now lies in the magnetic meridian. If the horizontal scale is divided into four quadrants, each of them reading from 0° to 90°, then rotate the upper part of the instrument through exactly 90° from the average reading to coincide with the vertical plane with the magnetic meridian.

The marked face of the instrument is, say, towards the east and the marked face of the needle is then towards the west.

(iii) *Measurement of dip.*

(a) The axle of the needle may not coincide with the centre of the vertical circular scale. Therefore, read both ends of the needle on the vertical scale.

(b) The magnetic axis of the needle may not coincide with the geometric axis. Therefore, reverse the needle on its bearings and read both ends of the needle.

(c) The zero line of vertical scale may not coincide with the horizontal. Therefore, rotate the instrument through 180°. Read both ends of the needle. Then reverse the needle on its bearings and read both ends of the needle.

(d) The centre of the axle may not coincide with the centre of gravity of the needle. Therefore, demagnetise* the needle by heating

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* For the best way of demagnetising hold the needle in the solenoid, switch on the alternating current and withdraw the needle to a great distance along the axis of the solenoid. Then switch off.

To magnetise, place the needle inside the solenoid and connect the apparatus to the A.C. mains. A sharp tap is given to the key so that the alternating current and remagnetise with opposite polarity by the method of *divided touch* by placing the needle on a grooved wooden frame so that the two magnetising magnets move over the wood surface and do not come in contact with the needle. Now place the needle back on its bearings and repeat the eight readings as before.

Find the mean of the sixteen readings which will give the true angle of dip.

Observations and Calculations

Enter thus :

Place........

(*A*) *Readings for setting plane of the Dip-circle in magnetic meridian.*

1 M. S. divn. of the Horizontal scale = ... degree.

....vernier divisions coincide with....M. S. divisions.

∴ 1 ver. divn. = ...degree.

Least count = ...degree.

Marked face of Dip circle faces	Marked face of the needle faces	Readings of Horizontal Scale						Average in deg.	*Average +90°
		Top of the needle			Bottom of the needle				
		M. S. in deg.	Ver.	Total in deg.	M. S. in deg.	Ver.	Total in deg		
South	South	...	...	...	...	...	...		
North	North	...	...	...	...	...	...		
North	South	...	...	...	...	...	...		
South	North	...	...	...	...	...	...		

---

flows momentarily through the solenoid. The polarity cannot be forecast. If the first attempt magnetises the needle in the wrong sense demagnetise and remagnetise. Test the polarity and continue demagnetising and remagnetising until the polarity is the right way round.

* **Make this column if needed.**

(*B*) *Readings for the angle of dip.*

Marked face of Dip circle faces	Marked face of the needle faces	Readings of Vertical scale, in degrees				Mean in deg. =true dip
		Polarity direct, End *B* dipping		Polarity reversed, End *A* dipping		
		Upper end	Lower end	Upper end	Lower end	
East	West	...	...	...	...	...
East	East	...	...	...	...	...
West	West	...	...	...	...	...
West	East	...	...	...	...	...

Result. The angle of dip in the laboratory= . . . .degree.

Precautions. (i) While swinging in a vertical plane, the needle often rolls on its axle and is displaced from the centre of the vertical circular scale. It is, therefore, advisable to raise frequently the needle off the agate edges and lower it again so that the axle may be brought back to the centre. (ii) While taking readings of the ends of the needle, avoid parallax error. (iii) The needle should not be touched with bare hands. (iv) Never touch the axle of the needle. The axle may be cleaned by pressing each end, in turn, into a piece of a pith. The knife-edges may be cleaned by rubbing lightly with pith. Be very careful in handling them as the axle and knife edges are both brittle.

ASSOCIATED EXPERIMENTS

1. Determine the vertical component of the earth's magnetic field in the laboratory, the value of H being given.

Hint. Perform the above experiment and determine the angle of dip, (δ°).

Now $\tan\delta=\frac{V}{H}$, where V is the vertical component of the earth's field.

$$\therefore \quad V=H.\tan\delta.$$

The value of H is given, so calculate V, in oersteds.

2. Determine the true dip in the laboratory by observing apparent dips.

Hint. Set the dip circle in any position (at some angle θ with the meridian) and determine the apparent dip, $\delta_1°$. Again set the dip circle at right angles to its former position and determine the apparent dip, $\delta_2°$. If $\delta°$ be the true dip, then

$$\tan\delta=\frac{V}{H},\ \tan\delta_1=\frac{V}{H\cos\theta}\ \text{and}\ \tan\delta_2=\frac{V}{H\sin\theta}$$

$$\therefore\quad \cot^2\delta=\cot^2\delta_1+\cot^2\delta_2.$$

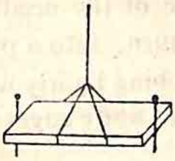
From this relation, calculate the true dip.

MAGNETIC AXIS OF A MAGNETISED BODY

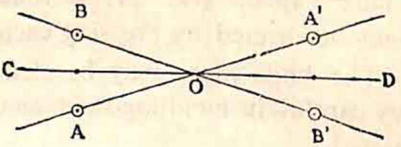
EXPERIMENT 5. **Determination of the magnetic axis of a magnetised box.**

Apparatus. Magnetised box, brass pins, compass, scale, drawing board, wax, and wooden stand and clamp.

Procedure. (i) Stretch a white sheet of paper on a drawing board and fix it in position by wax. By an unspun silk fibre suspend the magnetised box so that its plane is horizotal and slightly above the middle of the paper. Fix two long brass pins at the middle of both the ends of the box by means of wax, so that the pins are vertical in the suspended position of the magnet and are equally projected on upper and lower sides of the box (see fig. 5.12 a).



(Fig. 5.12 a)



(Fig. 5.12 b)

(ii) When the box comes to rest, fix brass pin A and A' vertically on the board so that the pins A and A' and the pins fixed to the box appear to be in the same straight line. Mark the positions of A and A' with small circles round them. Remove the pins A and A'.

(iii) Turn the box upside down so that the bottom face comes to top and again suspend it as before. But the pins attached to the box should not be disturbed. Next fix two brass pins B and B' on the board so that the pins B and B' and the pins fixed to the box appear to be in the same straight line. Mark the positions of B and B' with small circles round them. Remove the pins B and B'.

(iv) Remove the drawing board. Join A-A' and B-B'. Bisect the angle AOB by a line CD. Next bring the board below the suspended box so that the straight line BB' falls just below the pins attached to the box. Mark two points on the box opposite the points C and D. The line joining these marks will locate the magnetic axis of the magnetised box.

Precautions (i) Brass pins should be fixed vertically. (ii) The distance between the pin A and the nearest pin attached to the box should not be less than 10 cm. Similarly treat for other pins.

Note. The *magnetic moment* of the magnetised box can also be determined. For this, oscillate the box with a small amplitude and find the time period T by means of a stop-watch. Calculate its moment of inertia I about the suspension fibre. From the relation

$$T=2\pi\sqrt{\frac{I}{MH}},$$

calculate M. The value of H will be supplied.

ASSOCIATED EXPERIMENT

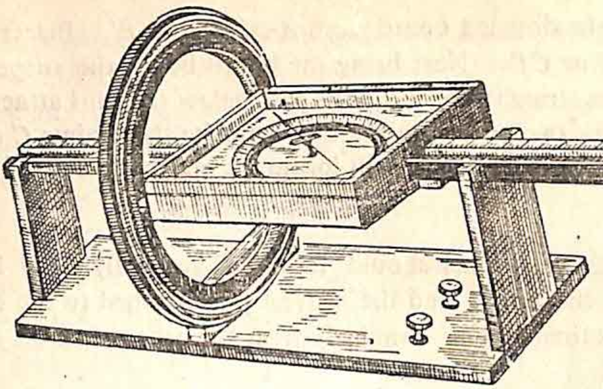
1. Determine the magnetic axis of the given short bar magnet hidden inside a wooden box and find its moment without the use of a magnetometer. Value of H will be supplied.

Hint. Perform the experiment as described in expt. 5.

EXPERIMENT 6. To study the variation of the magnetic field due to a circular coil with the distance along the axis.

Apparatus. Stewart and Gee Tangent galvanometer, rheostat (about 5 ohm), ammeter, accumulator, commutator, key and connecting wires.

Description of the apparatus. STEWART AND GEE TANGENT GALVANOMETER : It consists of a circular coil of few turns wound uniformly on a large circular wooden frame. The frame is fixed in a vertical plane on a horizontal stand as shown in the figure 5.13. The stand carries a deflection magnetometer which can slide on it in such a way that the centre of the magnetic needle always lies on the axis of the coil.



(Fig. 5.13)

The ends of the coil are connected to two binding terminals fixed to the horizontal stand.

Theory. The intensity of the magnetic field at any point on the axis of the coil carrying a current at a distance x from the centre of the coil is given by

$$F=\frac{2\pi n\ i\ r^2}{(x^2+r^2)^{3/2}},$$

where r is the radius of the coil, n the number of turns in it, and i the current (in e.m.u.) flowing through it.

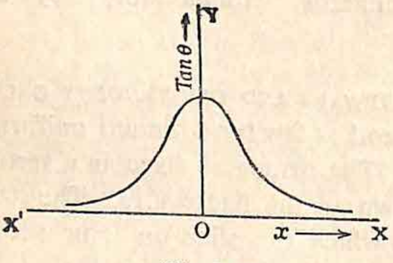
If the plane of the coil lies in the magnetic meridian, the field F is perpendicular to the earth's horizontal field H, because the field F is perpendicular to the plane of the coil. So the arrangement is in Tan-A position of Gauss. If the deflection of the needle, placed at a distance of x on the axis is θ, then

$$F=H\tan\theta.$$

Hence
$$F=\frac{2\pi n\ i\ r^2}{(x^2+r^2)^{3/2}}=H\tan\theta.$$

If i is kept constant, then since π, n and r are constants,

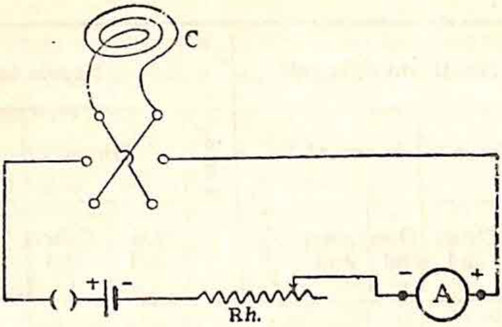
$$\tan\theta\propto\frac{1}{(x^2+r^2)^{3/2}}.$$



(Fig. 5.14)

If a graph be plotted between the different values of x on both sides of the coil and $\tan\theta$ (being proportional to F) then the curve will be of the type shown in fig. 5.14.

Procedure. (i) Connect a rheostat Rh and an ammeter A in series with the circular coil C as in figure 5.15.



(Fig. 5.15)

(ii) Level the galvanometer in the usual way.

(iii) Place the deflection magnetometer on the stand so that the centre of the magnetic needle is at the centre of the coil. Rotate the stand in a horizontal plane till the coil and the needle are in the same vertical plane. In this position the coil is in the magnetic meridian.

Next pass the current through the coil and adjust the rheostat so that the deflections of the needle is about 45° Now observe if the deflections obtained with direct and reversed currents are equal. If the deflections are unequal, rotate the coil till they are equal. This brings the coil exactly in the magnetic meridian.

(iv) By adjusting the rheostat make the deflection equal to 60° nearly. Read the ammeter and during the experiment this value of current should be kept constant. Read both the ends of the pointer. Reverse the current and again read both the ends of the pointer. The mean of these four readings gives the value of θ when $x=0$.

(v) Next shift the magnetometer by 2 cm on the right and find mean value of the deflections on passing the current. Read the distance of the needle from the centre of the coil as obtained from the left-arm scale reading at the centre of the coil.

(vi) Proceed by gradually increasing the distance by 2 cm and repeat process (v) for every such distance, till the deflection is reduced to 30°.

(vii) Repeat the measurements on the left side of the coil.

(viii) Plot a graph taking the distance, x in cm, along x-axis and $\tan\theta$ along y-axis. Take the distance (x) on the right side of the coil as *positive* along OX, and distance (x) on the left side of the coil as *negative* along OX' (see Fig. 5.14). The curve would show the variation of the field on both sides of the coil.

Observations

Enter thus :

No. of observations	Distance from the centre of the coil x (cm)	Needle on right side				Mean θ_R	Tan θ_R	Needle on left side				Mean θ_L	Mean θ_L
		Direct		Reversed				Direct		Reversed			
		One end	Other end	One end	Other end			One end	Other end	One end	Other end		
1													
2													
3													
4													
.													
.													
.													
.													
.													
10													

Precautions. (i) The plane of the coil should be in the magnetic meridian. (ii) The ammeter should be away from the galvanometer. (iii) The current should be maintained constant throughout the experiment. If necessary, the rheostat should be adjusted.

Note. The radius of the coil, r, can be obtained from the above experiment. For this purpose, draw a graph taking $\cot^{2/3}\theta$ along the x-axis and x^2 along the y-axis, which will be a straight line. The intercept on the y-axis will be equal to r^2 from which r can be obatained. For,

$$(x^2+r^2)^{2/3}=\left(\frac{2\pi n\, i\, r^2}{H}\right)\cot\theta$$

or

$$x^2=\left(\frac{2\pi n\, i\, r^2}{H}\right)^{2/3}\cot^{2/3}\theta-r^2.$$

ASSOCIATED EXPERIMENTS

1. Find the magnetic moment of the given bar magnet with the help of a tangent galvanometer and an ammeter.

Hint. (i) For this purpose take a Tangent-galvanometer of the Stewart and Gee type. Connect a rheostat *Rh* and an ammeter *A* in series with the circular coil C as in figure 5.15.

(ii) Place the deflection magnetometer on the stand so that the centre of the magnetic needle is at the centre of the coil and keep it there during the whole experiment. Now set up the coil with its plane vertical and parallel to the needle (i.e., in the magnetic meridian) as described in the above experiment.

(iii) (a) Now pass the current through the coil and adjust the rheostat so that the deflection of the needle is about 60°. Read the ammeter. Now place the given bar magnet on the east arm of the magnetometer at such a distance that the deflections are reduced to zero. Measure the distance between the centre of the magnet and the centre of the needle.

(b) Turn the bar magnet *upside down* and adjust its distance for null deflection. Again measure the distance between the centre of the magnet and the centre of the needle.

(c) Reverse the current and *reverse* the *pole* facing the needle. Adjust its distance for null deflection and note down the distance.

(d) Again turn the bar magnet *upside down* and adjust its distance for null deflection. Note down the distance.

(e) For the same current repeat the operations (a), (b), (c), and (d) by placing the bar magnet on the west arm.

Take mean of all the eight distances which will give *d* free from the errors.

Note that the current should be maintained constant for the whole operation (iii). If necessary, adjust the rheostat.

(iv) Decrease the current by instalments to decrease the deflection from 60° to 30° and repeat operation (iii). In each case note the value of current (i in amps.) and mean distance (d in cm) between the centre of the magnet and the centre of the needle.

Thoery. The intensity of the field F at the centre of the coil due to current i amp. flowing through the coil is given by,

$$F=\frac{2\pi\, ni}{10r},$$

where n = no. of turns in the coil, and r = radius of the coil.

The intensity of the field F' due to the bar magnet at the centre of the coil in the end-on position of the magnet is given by,

$$F' = \frac{2Md}{(d^2 - l^2)^2}$$

where M = magnetic moment of the bar-magnet,

l semi-magnetic length, and

d = distance between the centre of the magnet and the centre of the needle.

For null deflection, $F = F'$,

or
$$\frac{2\pi\, ni}{10r} = \frac{2Md}{(d^2 - l^2)^2}.$$

Hence,
$$M = \frac{\pi\, ni}{10r} \cdot \frac{(d^2 - l^2)^2}{d}.$$

Knowing n, r, l, i and d the magnetic moment M can be calculated.

Note. If the Stewart and Gee tangent galvanometer is not available, a horizontal board or a scale may be placed along east (and west) of the ordinary tangent galvanometer at the same height as that of the needle. The bar magnet must be placed along the axis of the coil to nullify the deflections.

Tabulate the observations thus—

Radius of the coil, r = ... cm.

No. of turns, n = ...

Semi-magnetic length, l = ... cm.

No. of observations	Current i, in amps.	Distance of the magnet								Mean d in cm	Magnetic moment M, in weber-cm	Mean M in weber-cm
		East arm				West arm						
		One pole facing the needle		Other pole facing the needle (when current is reversed)		One pole facing the needle		Other pole facing the needle (when current is reversed)				
		Face up	Face down	Face up	Face down	Face up	Face down	Face up	Face down			

2. Use a bar magnet to nullify the deflections in a tangent galvanometer due to currents flowing through its coil and hence find its magnetic moment.

Hint. If the ammeter is given, this expt. is similar to the expt. described in Ex. 1. So proceed as explained in Ex. 1.

If the ammeter is not given, first determine the value of current (i) in amp by noting the deflections from the formula given below,

$$i=\frac{10\,r\,H}{2\pi\,n}\tan\theta.$$

Knowing r, n and H (the horizontal component of earth's field), i can be calculated for different values of θ.

Now nullify each deflection as described in Ex. 1. Hence calculate the magnetic moment, M.

EXPERIMENT 7. **To study the variation of the magnetic moment of the given straight electromagnet with the current flowing through the coil.**

Apparatus. Deflection magnetometer, a solenoid, iron rod (about 50 cm long and 1 to 2 mm in diameter), a compensating solenoid, accumulator (one or two), an ammeter, a commutator, a key, a rheostat, and connecting wires.

Description of the apparatus. SOLENOID : It is a spiral of wire having many turns wound uniformly and close together on a glass tube (preferably about 40 cm long and of 1 cm external diameter for this expt). Both the ends of the tube are covered with cork having bores so that the iron rod can be fixed inside the tube along its axis.

Theory. When a current, i amp., flows through the solenoid, the field inside the coil is given by

$$F=\frac{4\pi\,ni}{10},$$

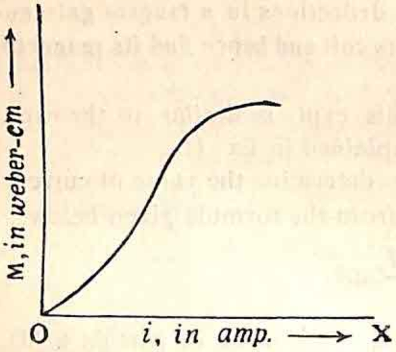
where n is the number of turns per cm of the solenoid. If now an iron rod is placed inside the solenoid, it will be magnetised by the magnetic field due to current and the system forms an *electromagnet.*

If the straight electromagnet is placed along the axis of the deflection magnetometer arranged in Tan-A position of Gauss, then for deflection θ of the needle,

$$\frac{2Md}{(d^2-l^2)^2}=H\tan\theta,$$

or

$$M=\frac{(d^2-l^2)^2}{2d}H\tan\theta,$$



(Fig. 5.16)

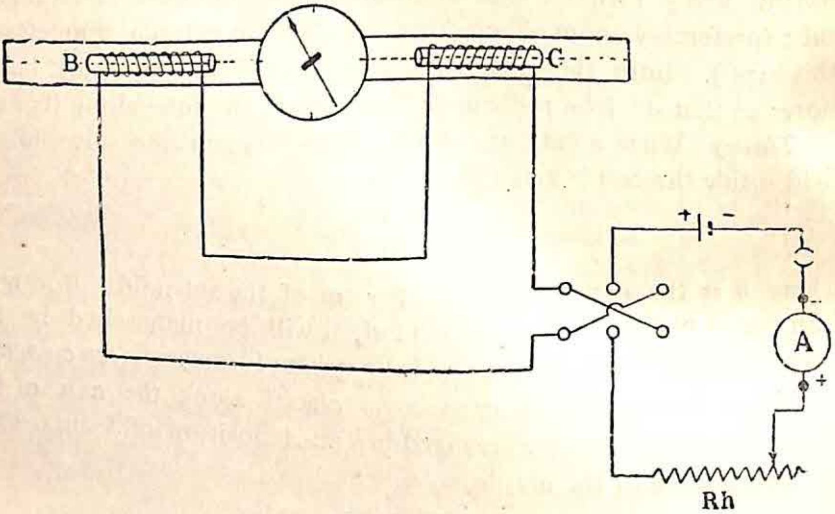
where M is the magnetic moment of the electromagnet, d the distance of the centre of the rod from the needle, $2l$ the length of the rod, and H the horizontal component of the earth's field.

The value of M changes as the current changes. If a graph be plotted between different values of M and the current, then the curve will be of the type shown in Fig. 5.16.

Procedure. (i) Set the deflection magnetometer in Tan-*A* position of Gauss as explained earlier.

(ii) Place the solenoid *B*, on the west arm along the axis of the magnetometer with its near end about 15 cm from the needle. Also place the compensating solenoid *C*, on the east arm along the axis of the magnetometer. Place the iron rod inside the solenoid *B* and if it is exactly along the axis, the deflection of the needle will not be affected. If there is deflection, adjust it so that there is no deflection.

(iii) Take out the iron rod. Connect the two solenoids in series and then arrange the circuit as shown in the Fig. 5.17.



(Fig. 5.17)

Insert the key and adjust the position of the compensating solenoid *C*, until there is no deflection of the needle for any current (adjusted by rheostat) up to the maximum current. Now the positions of *B* and

C should be kept fixed during the whole experiment. Remove the key.

(iv) Demagnetise the iron rod by hammering and place it inside the solenoid B, as before. Keeping the resistance maximum in the rheostat, insert the key. Now adjust the rheostat so that the deflection of the needle is about 30°. Note down the ammeter reading. Read both the ends of the pointer. Reverse the current and again read both the ends of the pointer. Take the mean of these four deflections.

(v) Increase the current so that the deflection is increased by about 5°. Note down the current (i) and mean deflection (θ).

(vi) In this way, go on increasing the current till the deflection is about 60°. In each case, note down the current (i) and the mean deflection (θ).

(vii) Determine d, the distance of the centre of the iron rod from the needle. It is the mean of the readings of the ends of the rod. Also the length ($2l$) of the rod will be given by the difference between these two readings.

(viii) Plot a graph taking current i, in amp. along x-axis and the magnetic moment M, in weber-cm, along y-axis. The resulting curve will be of the type shown in Fig 5.16. The curve would show the variation of the magnetic moment with the current.

Observations and Calculations

Enter thus :

$H = \ldots\ldots$ oersteds, $d = \ldots\ldots$ cm, $2l = \ldots\ldots$ cm.

No. of obs.	Current i in amp.	Deflection θ, in degrees					Tanθ	Magnetic moment, $M = \frac{(d^2 - l^2)^2}{2d} H \tan\theta$ in weber-cm
		Direct		Reversed		Mean θ		
		E-End	W-End	E-End	W-End			
1								
2								
3								
...								
...								
...								
10								

Precautions. (i) Do not decrease the current at any stage, nor switch it off (until the experiment is finished). (ii) The ammeter should be away from the deflection magnetometer.

EXPERIMENT 8. To draw the $I-H$ curve by Magnetometer for the given specimen.

Apparatus. A mirror magnetometer, a solenoid, a circular coil, a commutator, an ammeter, a rheostat, a plug key, and an accumulator.

Descriptons of special apparatus. (i) MIRROR MAGNETOMETER : This has a concave or plane mirror of circular shape of about 1 cm diameter. A magnetic needle is attached to the back of this mirror horizontally. The mirror is suspended from a torsion head. The whole arrangement is housed in metallic box like the one with a suspended galvanometer. A lamp and scale arrangement of exactly the same type as in a suspended coil galvanometer is used to note the deflection of the magnetic needle of the magnetometer on a linear scale placed at a distance of about one metre from the magnetometer needle.

(ii) SOLENOID : This is made by closely wounding copper wire of about 1 mm diameter, wrapped with cotton thread, on the outer surface of a glass or card-board tube of about 50 cm to one metre length and about 2 cm diameter. The coil is energised by a d.c. current. The specimen rod to be magnetised is suspended inside this solenoid.

(iii) CIRCULAR COIL : This is made over a ring of wood, having internal and external diameters of about 20 cm and 23 cm respectively, by wounding copper wire of about 1 mm diameter, wrapped with cotton thread, in the groove over the external circumference of the ring. This coil is energised by the same current which energises the solenoid.

Theory. If α be the cross-sectional area of the specimen of the iron rod, and I be the intensity of magnetisation of the rod, the pole strength at each end of the rod is $I\alpha$.

The magnetic force-field at the magnetometer needle M due to the pole A of the rod (Fig. 5.18) is $\frac{\mu_0 I\alpha}{4\pi d^2}$, where d is the distance of the pole from the needle. The magnetic force field at the pole B of the rod is $-\frac{\mu_0 I\alpha}{4\pi(d^2-l^2)}$ where l is the magnetic length of the rod. The horizontal component of this force-field is $-\dfrac{\mu_0 I\alpha d}{4\pi(d^2+l^2)^{\frac{3}{2}}}$. The resultant horizontal force-field at M is $\dfrac{\mu_0 I\alpha}{4\pi}\left\{\dfrac{1}{d^2}-\dfrac{d}{(d^2+l^2)^{\frac{3}{2}}}\right\}$. This is made to be at right angles to the intensity of the controlling field, f of the earth. The deflection of the magnetic needle θ is then given by the tangent law,

$$\frac{\mu_0 I\alpha}{4\pi}\left\{\frac{1}{d^2}-\frac{d}{(d^2+l^2)^{\frac{3}{2}}}\right\}=\mu_0 f\tan\theta$$

so that
$$I=\frac{4\pi f}{\alpha}\tan\theta\Bigg/\left\{\frac{1}{d^2}-\frac{d}{(d^2+l^2)^{\frac{3}{2}}}\right\}\text{ Am}^{-1}\ \ldots \qquad (1).$$

If the specimen is quite long, the term $d/(d^2+l^2)^{\frac{3}{2}}$ may be neglected, but preferably it may be calculated by taking l to be three-fourth of the length of the rod.

If the solenoid is disconnected from the circular coil (fig. 5.18), then if due to a current i_1 in the circular coil the deflection of the magnetometer be θ_1; then by the tangent law

$$\frac{\mu_0}{4\pi}\frac{na^2 i_1}{(a^2+x^2)^{\frac{3}{2}}}=\mu_0 f\tan\theta_1,$$

or
$$f=\frac{n\,a^2\,i_1}{4\pi(a^2+x^2)^{\frac{3}{2}}}\cot\theta_1\text{ Am}^{-1} \qquad \ldots \qquad (2),$$

where n = no. of turns in the circular coil, a = its mean radius, and x is the distance of the centre of the coil from the magnetometer needle.

f may be calculated from equation (2), and then bring this f in equation (1) I may be calculated by observing θ.

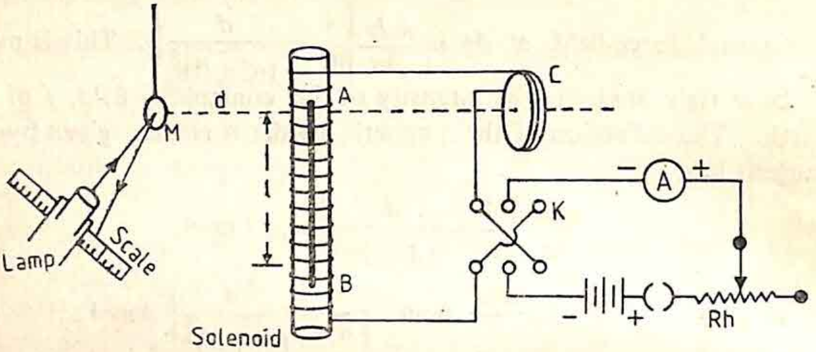
If n' be the number of turns per metre of the solenoid, the magnetising field intensity of the solenoid is

$$H=n'i\text{ Am}^{-1} \qquad \ldots \qquad (3).$$

H may be calculated in terms of the magnetising current i.

Thus it is possible to get values of I for the specimen for different values of H and hence plot a curve with I against H. This turns out to be a loop the area of which is a measure of the excess of work done on the material over that done by it per unit volume per cycle of magnetisation.

We find that with f, α, d and l in the equation fixed, $I\propto\tan\theta_1$ and if θ does not exceed 10°, then within an error of less than 1%, $\tan\theta=\theta$; so that $I\propto\theta$. Also by the equation (3) $H\propto i$. Hence the plot of deflection against the magnetising current will represent the $I-H$ curve.



(Fig. 5.18)

Procedure. (i) Arrange the mirror magnetometer on a high stand and the lamp and scale arrangement on a table.

(ii) Arrange the solenoid vertically at a distance of about 1 to 2 metres from the magnetometer M by clamping it to a wooden clamp placed over a high stand such that its top end is a little above the needle of M, and also keep its whole length in the vertical equitorial plane of needle (a plane perpendicular to the magnetic meridian), as far as practical.

(iii) Arrange a cirular coil C vertically by clamping it with a wooden clamp over a high stand such that its plane is parallel to the magnetic meridian and its centre is nearly as high above the floor as is the height of the magnetometer needle. Connect this coil in series with the coil of the solenoid.

(iv) Connect the free end of the coil C and the free end of the coil of the solenoid to a circuit containing a commutator, ammeter, battery, plug key, and rheostat in series as shown in the diagram.

(v) Heat the specimen rod in fire and then lightly hammer it at different places over its length to demagnetise it.

(vi) Measure the length L of the specimen rod of iron with the help of a metre scale, and also measure the diameter of the specimen at ten places by taking direct and cross readings at every place with a screw gauge.

(vii) Without putting the specimen rod in the solenoid, pass electric current in the coil of the solenoid and hence in the coil C. Adjust the distance of the coil C until the deflection of the magnetometer needle becomes zero. Thus the magnetic force-field of the coil *C* neutralises the magnetic force-field of the solenoid at *M*.

(viii) Now suspend the specimen rod in the solenoid such that its upper end is above the centre of the needle *M* by about $\frac{1}{8}$ of its length.

(ix) Switch on the circuit with maximum resistance in the rheostat and hence with minimum current in the winding of the solenoid which will be read from the ammeter. Note the deflection of the spot of light over the scale of the lamp and scale arrangement.

(x) Go on increasing the current in steps taking the ammeter reading for the current and keep on noting the corresponding reading of the deflection of *M* until a situation is reached when the deflection changes insignificantly with the increase of current.

(xi) Now decrease the current in steps finally to zero and keep on noting the corresponding deflection of *M*.

(xii) Now reverse the direction of current with the help of the commutator to make negative in sign and again go on increasing the current in steps taking the ammeter reading (always give a negative sign to it) for the current and keep on noting the corresponding reading of deflection until a situation is again reached when the deflection changes insignificantly with increase of the reversed current. Use a negative in the readings of the deflections in reversed direction.

(xiii) Now decrease this reversed current in steps finally to zero and keep on noting the corresponding deflection of *M*.

(xiv) Again reverse the direction of current with the help of the commutator and go on increasing the current in steps and keep on noting the corresponding reading of deflection of *M* until the deflection changes insignificantly with the increase of current. This brings you to the end of one hysteresis cycle.

(xv) Plot the deflection of the light spot as recorded on the scale of the lamp and scale arrangement against the magnetising current. The resulting curve represents the *I-H* curve within a reasonable limit of accuracy as discussed in the theory. Also as detailed in theory values of *I* and *H* can be calculated if the actual *I-H* curve is required from which the hysteresis loss per cycle per unit volume may also be determined.

Observations

Material of the specimen rod = ...

Length of the specimen rod = (i)....
(ii)....
(iii).... } Mean length = ...

$d = ...,\ L = ...,\ l = \frac{8}{4}L = ...,\ x = ...$

Diameter of the specimen rod (if needed)—

No. of obsv.	Main scale reading (M. S.)	L.C.	Vernier coincidence (V. C.)	V. C. ×L. C.	Total (M.S.+V.C.×L.C.)
1 D					
1 C					
2 D					
2 C					
...					
...					
...					
10 D					
10 C					

Mean diameter = ...

Area of the cross-section = ...

Readings for magnetometer deflection and magnetising current—

No. of obsv.	Reading of ammeter (i in ampere)	Reading of magnetometer deflection
1		
2		
...		
...		
...		

Calculation for f (if needed)—

For such an auxiliary experiment has to be done as indicated in the theory in which only the circular coil C (not the solenoid) will be in the circuit and the specimen rod will be out,

$$n = \ldots,\ a = \left.\begin{matrix}(i)\ldots\\(ii)\ldots\\(iii)\ldots\end{matrix}\right\}\ \text{Mean} = \ldots,\ x = \ldots$$

No. of observations	Current i_1	Deflection θ_1	$\cot\theta_1$	f	Mean f
1					
2					
...					
...					
...					
5					

Calculation of H (if needed)—

$$n' = \dots.$$

No. of observations	i in amp.	H in Am^{-1}
1		
2		
...		
...		
...		
...		

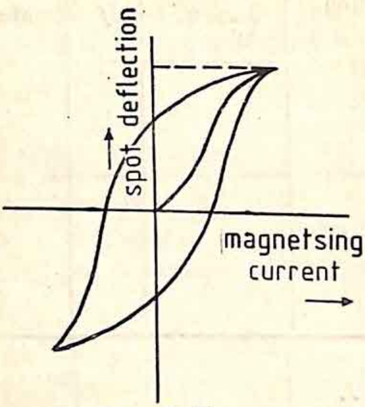
Calculation of I (if needed)—

$$\frac{4\pi f}{\alpha} \Big/ \left\{ \frac{1}{d^2} - \frac{d}{(d^2+l^2)^{3/2}} \right\} = \dots.$$

The distance between the magnetometer needle and the scale $= D = \dots$.(if needed)

No. of observations	H Am^{-1}	Magnetometer deflection $\theta = \frac{1}{2}\,\frac{\text{spot defl.}}{D}$	$\tan\theta$	I Am^{-1}
1				
2				
3				
...				
...				
...				

Results and Calculations

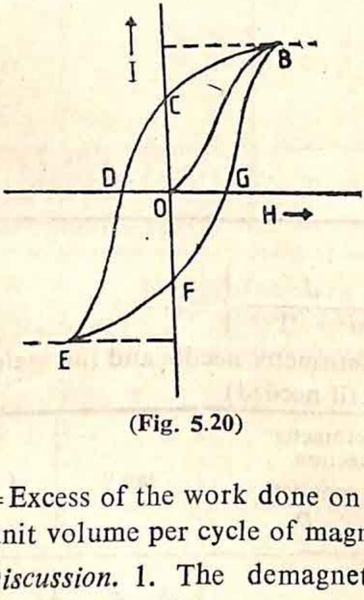


(Fig. 5.19)

If the aim of the experiment is to be limited to obtain just the nature of the *I-H* curve of the specimen, it will suffice to plot the spot deflection against the magnetising current to obtain a curve as shown in Fig. 5.19.

If the actual *I-H* curve has to be necessarily obtained *I* has to be plotted against *H* as shown in Fig. 5.20.

The value *OD* on the scale of $H = \ldots = $ the coersive force for the specimen.



(Fig. 5.20)

The value of the residual magnetism on the *I* scale

$= \ldots$

= the residual magnetism for the specimen.

Value of one small square on the graph paper on the *H* and *I* scales $= \ldots = a$.

The number of small squares within the loop

$BDEGB = \ldots = b$.

Area of the loop

$= a \times b = \ldots$ Joule per cycle per cubic metre

= Excess of the work done on the material over that done by it per unit volume per cycle of magnetisation.

Discussion. 1. The demagnetisation effect on the specimen needs to be taken into account.

Due to the demagnetisation effect the correct value of H = observed value of $H - NI$ where N is a constant for the specimen whose value depends upon its length to diameter ratio of the specimen. For a specimen of iron of length to diameter ratio equal to 100, $N = 0{\cdot}0054$. Thus the correction H due to the demagnetisation effect may not be significant.

2. The specimen is magnetised to some extent even in the absence of any magnetising current in the solenoid. This is due to the vertical component of the earth's field. To eliminate this disturbance a second coil may be wound over the solenoid and a current through it may be adjusted until, with the demagnetised specimen in the solenoid and with no solenoidal current, the deflection of the magnetometer becomes zero.

3. When $\theta = 10^\circ = 0{\cdot}175$ radian, and $\tan 10^\circ = 0{\cdot}176$. Hence, within an error of less then 1%, we may assume $\tan\theta = \theta$. As the mirror is rotated by 10°, the reflected beam is rotated by 20°. So for a mirror at a distance of 1 metre from a scale, the deflection of the spot of a reflected beam $= 36{\cdot}4$ cm which is sufficient to conduct the experiment. Hence, the distance *d* of *M* from the solenoid may be chosen to give a deflection of the spot up to 35 cm over a scale placed at over 1 metre from *M* for the saturation value of *I*. Then $\tan\theta$ may be safely approximated to θ.

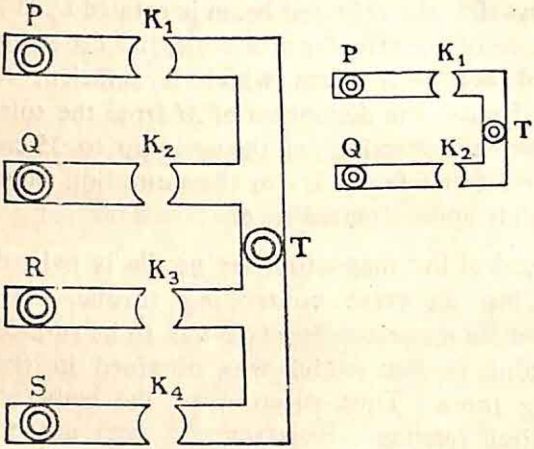
4. The suspension thread of the magnetometer needle is twisted by its deflection, providing an extra controlling torque. To eliminate this torque the whole magnetometer box has to be rotated to bring the deflection reading to that which was obtained in the presence of the deflecting force. Thus rotation of the body of instrument gives the required reading. However, this may not be necessary for a suitably chosen suspension thread for which the couple per unit twist is small enough to be neglected.

□□□

6. ELECTRICITY

SOME ELECTRICAL EQUIPMENTS AND INSTRUMENTS

1. Four-way and two-way Keys



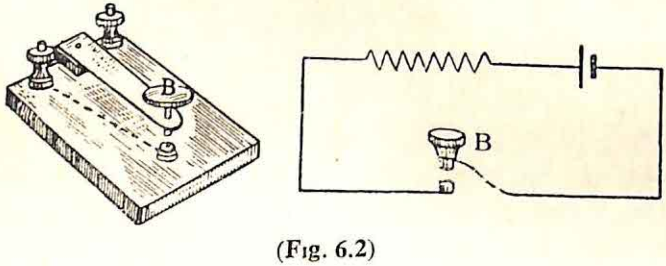
(Fig. 6.1)

A four-way key consists of four blocks of metal P, Q, R, S fixed over an ebonite board. Another block of metal T in front of these forming four keys K_1, K_2, K_3 and K_4 such that when K_1 is closed, connection between P and T is obtained while K_2, K_3 and K_4 remain disconnected. Similarly, when K_2 is closed K_1, K_3 and K_4 remain disconnected, and so on. Thus this type of key permits one of the four terminals to be connected to a common terminal.

A two-way key is like a four-way key with two keys only.

2. Tapping Key

It consists of a metal spring arranged over an ebonite base having



(Fig. 6.2)

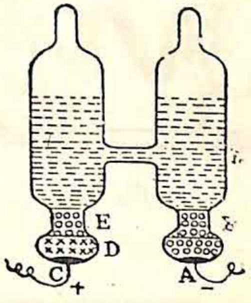
a metal point which when pressed from above makes contact with another metal point which can be connected to a wire by a screw. The spring may be connected to a wire with the help of the screw attached to it. On pressing the spring downwards contact is made to close a circuit. When the pressure is released the circuit is broken.

3. Standard Cadmium Cell

It is a chemical cell having an e. m. f. of 1·0183 volts at 20°C. At any other temperature its e. m. f. is given by

$$E_t = [1{\cdot}0183 - 4{\cdot}06 \times 10^{-6}\,(t-20)] \text{ volts.}$$

Its internal resistance is of the order of 900Ω. The special features of this cell are its low temperature coefficient, long life, and capability of quick recovery in case a large current is accidentally drawn from it. However, it must be remembered that the cell should be used in as nearly an open circuit condition as possible to enable it to provide a standard reference voltage for a long time. A current of more than 10^{-6} ampere must never be drawn from this cell.

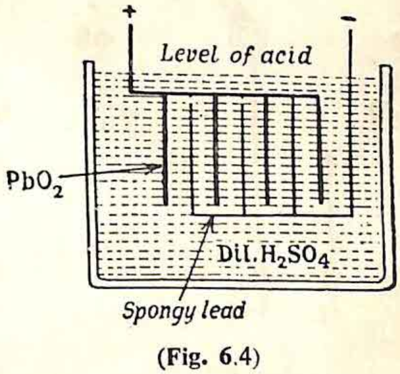


(Fig. 6.3)

The cell is made of an *H*-shaped glass vessel containing mercury (*C*), a paste of mercurous sulphate, cadmium sulphate and mercury (*D*) and cadmium sulphate crystals (*E*) on its positive polarity side. On its negative polarity side is placed amalgam of mercury and cadmium (*A*) and cadmium sulphate crystals (*B*). A saturated solution of cadmium sulphate is the electrolyte of the cell which connects the two limbs of the vessel. The mercurous sulphate in the paste of the limb having positive polarity is the depolariser in the cell.

4. Lead Accumulator (Storage Cell)

This consists of a set of positive potential plates of lead peroxide and a set of negative potential plates of spongy lead, both in the form of grids. The electrodes are placed in dil. H_2SO_4 of Sp. gr. 1·2. When fully charged the e. m. f. of the accumulator is about 2·2 volts. However, it gives an e.m.f. of about 2 volts to a circuit for quite a long time. It

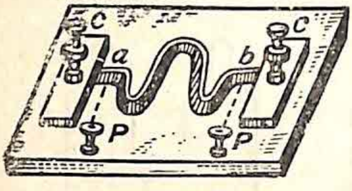


(Fig. 6.4)

needs recharging after its e. m. f. falls to 1·9. The specific gravity of a discharged accumulator falls below 1·18.

As a lead accumulator has a very low internal resistance of the order of 0·0001 ohm, a very high current will be drawn from it if it is short-circuited. This may even damage the cell permanently.

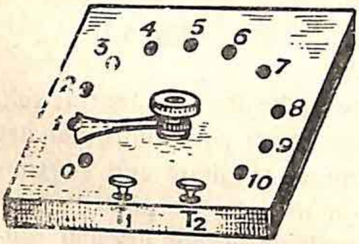
5. Standard Low Resistance



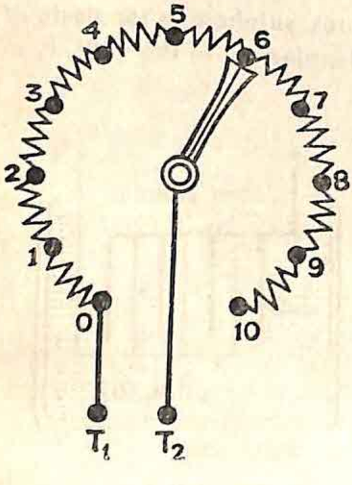
(Fig. 6.5)

In a standard low resistance there is a wavy plate of manganin having terminals $C-C$ at its ends. These terminals are known as the current terminals. Two special points *ab* on the plate are connected to two other terminals $P-P$. These terminals are called the voltage terminals. The value of the standard resistance is written by the side of the plate.

6. Dial Pattern Resistance Box



(Fig. 6.6)

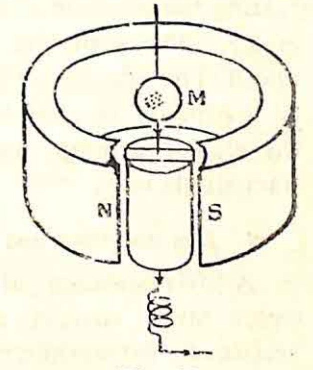


(Fig. 6.7)

The box of a dial pattern resistance is usually made up of ebonite. There are several pegs of brass on the box arranged at equal distances. Between the pegs resistance coils of gradually increasing values are connected in series (see figure). The first terminal T_1 is the free end of these resistances connected in series. There is another terminal T_2 which is connected to a rotary arm at the middle of the box. The rotary arm carries a spring and its free end presses against the brass pegs. The resistance between terminals T_1 and T_2 depends upon the position of the rotary arm. The value of the resistance written near the peg at which the rotary arm rests is the resistance between the terminals T_1 and T_2.

7. Moving Coil Galvanometer

A moving coil galvanometer normally used in Physics Laboratories consists of a light weight rectangular coil wound on a light conducting frame and suspended by a phosphor strip and held from beneath by a fine spiral between the concave pole of a permanent horse-shoe magnet. There is a cylindrical soft iron core in the middle of the coil to make the field of the magnet radial. The current enters the galvanometer coil through the fibre suspending the coil and leaves the coil through the spiral holding the coil at its other end. The upper end of the suspension is connected to the torsion head of the instrument and the lower end of the spiral holding the coil is fixed to hold the coil in position.

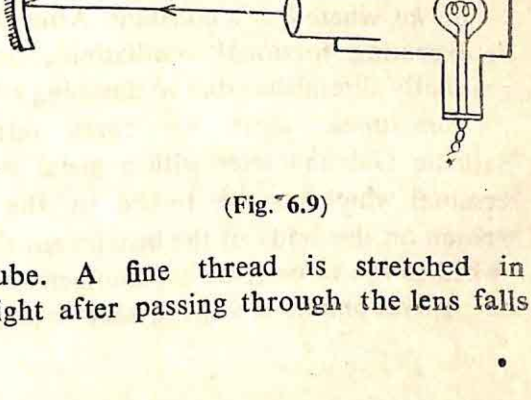


(Fig 6.8)

When an electric current flows through the coil, the coil experiences a deflecting couple due to the action of the magnetic field on the current. When this couple is counterbalanced by the opposing couple due to the torsion of the suspension and the spiral, the coil comes to rest. There is a small concave mirror attached to the suspension so that the rotation of the coil may be noted by the use of a lamp and scale arrangement of the type described below.

8. Lamp and Scale Arrangement

This consists of a horizontal milli-metre scale marked over a long narrow plate of ground glass, and an electric lamp. The scale is mounted horizontally over a vertical stand and its height can be adjusted. The lamp consists of a 4 volt electric bulb arranged inside a metal tube. Another metal tube with a converging lens fitted to it is pushed inside this tube. A fine thread is stretched in front of the lens so that light after passing through the lens falls



(Fig. 6.9)

over the concave mirror attached to the suspension of the galvanometer and forms the image of the thread on the scale. The image is focussed by moving the lens of the lamp unit in or out, and by adjusting the position of the lamp and scale with respect to the galvanometer. The scale and the lamp are usually mounted on the same stand. The filament of the bulb of the lamp unit is fed from a battery of 4 volts or by a 220 to 4 volts step down transformer. Sometimes the scale, the lamp, and the transformer are assembled as a compact single unit.

9. Low Resistance and High Resistance Galvanometers

A low resistance galvanometer is used to detect and measure relatively large current and low potential differences, while a high resistance galvanometer is used to detect and measure relatively weak current and large potential differences.

As a high resistance galvanometer has a large number of turns, even a small current through it would produce a large deflection of the coil. Thus a high resistance galvanometer is current-sensitive. A low resistance galvanometer has a smaller number of turns and even a small potential difference applied to these turns causes a large current to flow through the coil due to which a large deflection of the coil is obtained. Thus this type of galvanometer is voltage-sensitive.

10. Ballistic Galvanometer of Moving Coil Type

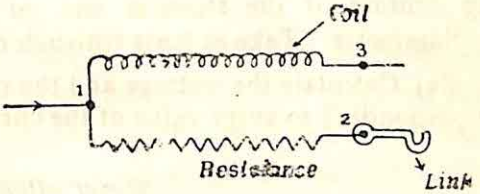
A ballistic galvanometer measures the quantity of charge which passes through its coil while a current flows through it for a very short time. The moving coil type of ballistic galvanometer is similar in construction to a high resistance current-measuring moving coil galvanometer except that the coil is wound on a light wooden frame. When a charge q passes momentarily through the coil of the galvanometer, a throw θ of the coil is noticed. q and θ are related by the relation,

$q = k\theta$, where k is a constant. After the first throw, the coil keeps on executing torsional oscillations, but the amplitude of the throw gradually diminishes due to damping effect on the coil.

Sometimes, there are three terminals on the body of a Ballistic Galvanometer with a metal strip attached to the second terminal which can be linked to the third terminal. It is also written on the body of the instrument that if the third terminal is linked to the second, the galvanometer becomes 'aperiodic'. An aperiodic galvanometer is a 'head beat' type galvanometer whose moving part comes to rest immediately after the current through the coil ceases.

The link when connected to the third terminal puts up a resistance parallel to the coil of the galvanometer Thus the electromagnetic damping current flowing through the closed circuit of the coil and the resistance due to the motion of the coil opposes the motion of the coil and brings it to rest soon after the main current through the coil is cut off.

The coil of a ballistic galvanometer when short circuited by an external short circuiting key quickly comes to rest on account of the electromagnetic damping current induced in the coil, opposing the movement of the coil.



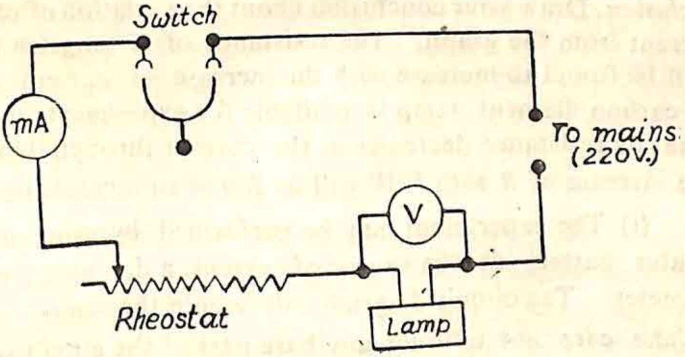
(Fig 6.10)

EXPERIMENT 1. **To measure the wattage and the resistance of an electric lamp carrying different currents.**

Apparatus. A 220 V electric bulb of 25 watts, an A. C. ammeter of 0—250 mA range, an A. C. voltmeter of 0—250 V range, a bulb holder, a switch and a rheostat of about 500 Ω and more than 250 mA rating.

Theory. If V be the potential difference measured across the bulb when a current I flows through its filament, the wattage of the lamp will be $W=VI$ and the resistance R of the filament will be given by $R=V/I$.

Currents of different strengths will heat the filament by different



(Fig. 6.11)

amounts. As the resistance of a wire increases with the increase of temperature, the resistance of the electric lamp would increase with the increase of current flowing through it.

Procedure. (i) Make connections of the different apparatuses as shown in the circuit diagram.

(ii) Keep the resistance of the rheostat in the circuit at its maximum value first and note the voltage V across the bulb from the voltmeter. Also note the reading of the current in the milliammeter.

(iii) Slowly increase the current in the circuit by moving the sliding contact of the rheostat and go on reading the voltmeter and milliammeter. Take at least ten such readings.

(iv) Calculate the wattage and the resistance of the electric lamp corresponding to every value of the current flowing through it.

Observations

No. of observations	Reading of voltmeter (V)	Reading of milliammeter (mA)	Current in Ampere (I)	Wattage (W)	R Ω
1	150	148	0·148	22·2	1013·5
2					
3					
⋮					
10					

Graph. Plot a graph with current on x-axis, and resistance on y-axis.

Conclusion. Draw your conclusion about the variation of resistance with current from the graph. The resistance of a tungsten filament lamp will be found to increase with the increase of current through it. If a carbon filament lamp is available for experiment, it will be found that its resistance decreases as the current through it increases. With the increase of R with I, W will be found to increase with I.

Note. (i) The experiment may be performed by using a 6 volt accumulator battery as the source of current, a d.c. ammeter and a d.c. voltmeter. The circuit diagram will remain the same.

(ii) Take care not to touch any bare part of the circuit when an A. C. main is used. Careless touching will give a shock.

ASSOCIATED EXPERIMENTS

1. To determine the wattage of an electric bulb.

Hint. As wattage, $W = V \times I$, its value may be determined as in Expt. No. 1 by noting the voltmeter and milliammeter readings as the current through the bulb is increased.

EXPERIMENT 2. To determine the temperature coefficient of resistance of a wire.

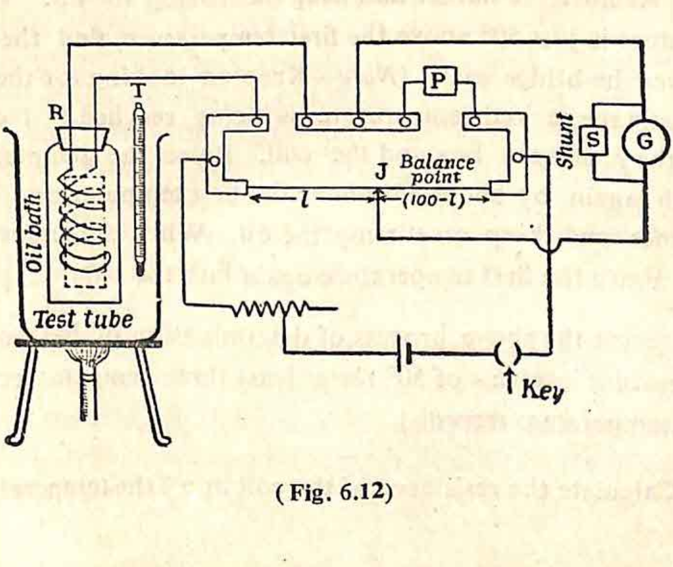
Apparatus. A thermometer reading up to 250°C, a resistance wire doubly wound over a mica plate and placed in a hard glass test tube, meter bridge, a cell, rheostat, suspended coil galvanometer with lamp and scale arrangement, oil bath, and a resistance box containing units and fractional resistances.

Theory. If R_0 and R_t be the resistance of a wire at 0°C and t°C respectively, and α be the temperature coefficient of resistance of the wire over this range of temperature, then very approximately,

$$R_t = R_0\,(1 + \alpha t).$$

Let the resistance of the wire measured at t_1°C be R_{t_1} and R_{t_2} be the resistance measured at t_2°C. Then,

$$R_{t_1} = R_0\,(1 + \alpha t_1), \quad \text{and } R_{t_2} = R_0\,(1 + \alpha t_2),$$



(Fig. 6.12)

so that
$$\frac{R_{t_2}}{R_{t_1}}=\frac{1+\alpha t_2}{1+\alpha t_1},$$

and hence
$$\alpha=\frac{R_{t_2}-R_{t_1}}{R_{t_1}t_2-R_{t_2}t_1}.$$

Procedure. (i) Arrange an oil bath over a tripod stand and immerse the test tube enclosing the resistance coil in the bath. Also immerse a thermometer inside the bath to read its temperature, and a stirrer to stir the oil.

(ii) Make the circuit with the apparatus assembled according to the circuit diagram given above.

(iii) Keep the jockey J at the middle point of the meter-bridge wire and adjust the resistance in the resistance box P until the deflection in the galvanometer is minimum. Now adjust the position of the jockey to find the balance point. Interchange the resistance box and the coil and determine the balance points again. Note the temperature of the bath. (This is the first temperature.)

(iv) Now heat the oil of the bath stirring it with a stirrer until its temperature rises by about 55° above the first temperature as recorded above. Remove the burner and keep on stirring the oil. When the temperature is just 50° above the first temperature, find the balance point over the bridge wire. (*Note*—Keep on looking for the balance point while the desired temperature is being reached.) Now interchange the resistance box and the coil. Raise the temperature of the bath again by about 55° above the first temperature. Remove the burner and keep on stirring the oil. When the temperature is just 50° above the first temperature again find the balance point.

(v) Repeat the above process of determination of balance points at temperature intervals of 50° for at least three temperatures above the first temperature recorded.

(vi) Calculate the resistance of the coil at all the temperatures.

Observations

No. of obs.	Temperature (t°C)	Position of the resistance		Balance point		Resistance in Ω	Mean Resistance in Ω (R)	
		Unknown	Known	(l or l')	$(100-l)$ or $(100-l')$			
1	$x=$	(i) Left (ii) Right	Right Left				...... $=R_1$	A
2	$x+50$	(i) Left (ii) Right	Right Left				...... $=R_2$	B
3	$x+100$						...... $=R_3$	A
4	$x+150$						...... $=R_4$	B

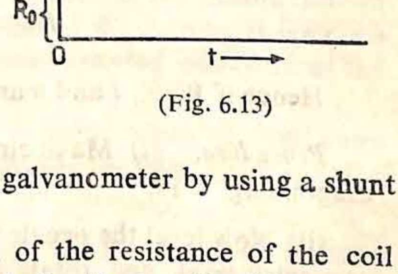
Calculation.

$$\text{Value of } \alpha \text{ (set A)} = \frac{R_3-R_1}{R_1(x+100)-R_3x} = \ldots\ldots$$

$$\text{Value of } \alpha \text{ (set B)} = \frac{R_4-R_2}{R_2\,(x+150)-R_4\,(x+50)} = \ldots\ldots$$

Mean $\alpha = \ldots\ldots\ldots$

Graph. Draw a graph with temperature on x-axis, and resistance on y-axis. This will be a straight line. The slope of this line will be $R_0\alpha$, and its intercept on y-axis will be $R_0\alpha$, if the origin of the graph is taken at $t=0$ and $R=0$. From the values of R_0 and $R_0\alpha$ obtained from the graph α can be calculated.



(Fig. 6.13)

Note. (i) Take care to protect the galvanometer by using a shunt across it.

(ii) The accuracy in determination of the resistance of the coil will improve if end-corrections are made for the length of the meterbridge wire. Hence the end-corrections λ_1 and λ_2 for the meter-bridge wire P should be first determined following procedure discussed in Expt. No. 11. Then, R should be calculated from the relation,

$$R=\frac{l+\lambda_1}{(100-l)+\lambda_2}\times P.$$

$$R=\frac{(100-l_1)+\lambda_2}{l_1+\lambda_1}\times P.$$

(iii) The experiment can be also performed with a Carey Foster Bridge, as discussed under the experiment "To construct a one ohm coil".

EXPERIMENT 3. To determine the Reduction factor of a tangent galvanometer using a copper voltameter.

Apparatus. Tangent galvanometer, copper voltameter, ammeter (0 – 1 ampere range), rheostat, commutator, plug key, accumulators (two, each of 2 volts), stop watch, physical balance, and weight box.

Theory. The deflection θ of the tangent galvanometer needle due to flow of a current of C ampere is given by

$$C=K\tan\theta, \quad \text{.. (1)}$$

where $K=$ the reduction factor of the tangent galvanometer, and obviously it is the current for 45° deflection.

If this current flows through a copper voltameter for t seconds, and if during this time W kg of copper is deposited over the cathode of the voltameter, then

$W=CZt$, where $Z=$ Electro-chemical equivalent of copper in **kg/** Coulomb. .. (2)

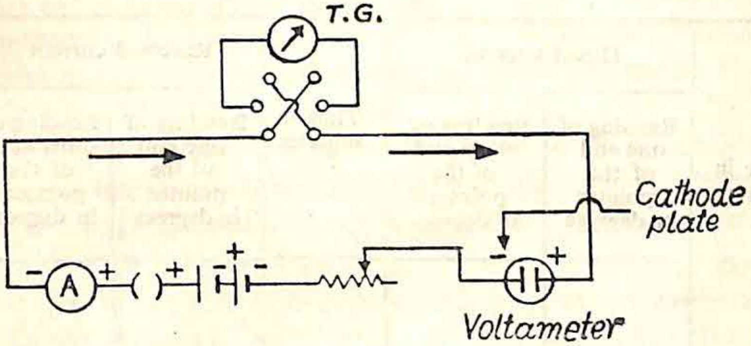
From equations (1) and (2),

$$K=\frac{W}{Zt.\tan\theta}\text{ amp.} \quad \text{... (3)}$$

Hence if W, Z, t and θ are known, K can be calculated.

Procedure. (i) Make circuit connections as shown in the circuit diagram fig. 6.14.

(ii) Now level the needle box of the galvanometer with the help of a spirit level, and rotate the coil of the galvanometer to make it parallel to the magnetic needle in the needle box. Keeping the coil now fixed to this position, rotate the needle box until the ends of the pointer attached to the magnetic needle become parallel to the 0 – 0 mark.



(Fig. 6.14)

(iii) Now take out the cathode plate of the voltameter, and clean it properly by rubbing it gently with zero paper. Dip it in dil. HNO_3 and then wash it with clean water and distilled water. Dry the plate, and then weigh it.

(iv) Take a plate (dummy cathode) of the same type as the cathode, and insert it inside the voltameter to dip its surface upto about 30 sq. cm inside the copper sulphate solution of the voltameter. Plug in the key to complete the circuit and adjust the rheostat to get a reading of current of about ½ ampere in the ammeter. Make sure that this current gives a deflection of the tangent galvanometer reading between 30° and 60° only.

(v) Now take the plug out of the key to break circuit. Remove the dummy cathode, and place the real clean cathode in its position. Plug in the key and start the stop watch simultaneously. Read the deflection of the pointer of the galvanometer needle in both quadrants. Keep on recording the readings of the pointer at intervals of 5 minutes alternately in the direct and reversed positions of the commutator.

(vi) Take the key out to stop the current when it has flown through the circuit for exactly 30 minutes as read from the stop watch.

(vii) Now take out the cathode plate and clean it with distilled water. Then dry it by pressing it gently between the folds of blotting paper. Also gently blow dry air over it to dry it completely. After that take the weight of the plate.

Observations

	Direct current			Reversed current		
Time in minutes	Reading of one end of the pointer in degrees	Reading of other end of the pointer in degrees	Time in minutes	Reading of one end of the pointer in degrees	Reading of other end of the pointer in degrees	Mean deflection θ in degrees
0			5			
10			15			
20			25			
30			—			

Time of current flow, $t = 30$ minutes $= 1800$ seconds.

Weight of cathode plate before copper deposition $= \ldots.$ gm $= W_1$

Weight of cathode plate after copper deposition $= \ldots.$ gm $= W_2$

Weight of copper deposited $= W_2 - W_1 = W = \ldots.$ gm.

Calculations.

Electro-chemical equivalent of copper

$Z = 329 \times 10^{-9}$ kg/Coulomb

$\therefore\ K = \ldots\ldots$ amp.

Further, $K = \dfrac{Br}{\mu_0 n}$, r = radius of the coil $= \ldots.$ m.

n = number of turns of the coil $= \ldots.$

B = horizontal component of earth's field $= \ldots.$ Tesla,

and $\mu_0 = 4\pi \times 10^{-7}$ H/m.

$\therefore$ By direct calculation,

$K = \ldots.$ amp.

Note. (i) It can be shown that when the deflection of the tangent galvanometer needle is 45°, the percentage error in value of current determined will be minimum for an error in reading the deflection of the needle. Hence, efforts should be made in this experiment to adjust the current to get a deflection of 45° of the galvanometer needle.

(ii) The galvanometer deflection may be poor if the amount of solution in the voltameter is insufficient, and if the total e.m.f. of the accumulators is inadequate. Hence to have sufficient deflection of the galvanometer more solution may be added and the number of accumulators may also be increased.

(iii) Proper setting of the galvanometer coil in the magnetic meridian is very important. Any deviation from the proper setting will result in large difference in deflection of the galvanometer when current through it is reversed.

(iv) The use of Pohl type of commutator is recommended as this will provide the case of quick change of the direction of current.

ASSOCIATED EXPERIMENTS

1. To use a copper voltameter to find the mean diameter of the coils of the tangent galvanometer. (The value of *B* will be supplied, but no ammeter will be supplied.)

Hints. The reduction factor k of the tangent galvanometer is given by

$k=\frac{Bd}{\mu_0 n}$, where d = mean diameter of the coils, in metre,

n = no. of turns of the coils,

B = Horizontal component of the earth's field, in Tesla,

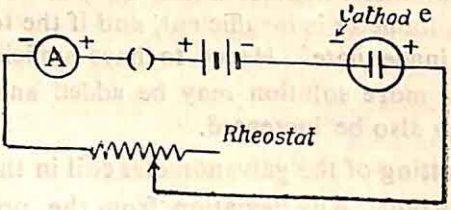
and μ_0 = permeability of the free space $= 4\pi \times 10^{-7}$ H/m.

So that, $$d=\frac{\mu_0 nk}{B} \text{ metre}$$

Determine the value of k by the method described in Expt. No. 3. As n is known and the value of B is supplied, d can be easily calculated after the value of k has been determined.

2. Measure the electrochemical equivalent of copper.

Hints. If C amperes be the current flowing in the circuit containing a copper voltameter, then in t secs. the quantity W gm of copper deposited on the cathode plate of the voltameter will be given by $W = CZt$, where Z is the electro-chemical equivalent of copper.



(Fig 6.15)

Hence, if by experiment, values of W, C, and t are obtained, then the value of Z can be calculated from the relation

$$Z = \frac{W}{Ct}.$$

For the experiment follow the following procedure :

(i) Make circuit connection according to the diagram given above.

(ii) Clean and dry the cathode plate by the method described in Expt. No. 3, and weigh it by method of oscillation.

(iii) First connect the dummy cathode to the voltameter allowing about 30 sq. cm of it to dip in the solution. Plug in the key and adjust the rheostat to obtain a reading of $\frac{1}{2}$ ampere in the ammeter.

(iv) Plug out the key and remove the dummy cathode. Connect the clean cathode plate to the voltameter now. Plug in the key and start a stop watch simultaneously. Allow the current to flow for a measured 30 minutes and after exactly 30 minutes plug out the key. Maintain the value of the current at $\frac{1}{2}$ ampere by slight adjustment of rheostat while the current flows for the total length of 30 minutes. Thus the value of C in the experiment is 0·5 ampere. The value of t will be 1800 seconds.

(v) Now clean and dry the cathode plate and the copper deposited over it by the method described in Expt. No. 3. Weigh the cathode with the copper deposited by the method of oscillation. The difference between this weight and the weight of the cathode plate before the copper is deposited over it is the weight W kg of copper deposited. Hence,

$$Z = \frac{W}{0{\cdot}5 \times 1800} = \frac{W}{900}.$$

3. To check the correctness of any graduation of the given ammeter by a copper voltameter or to measure a current by deposition of ions.

Hints. This experiment is exactly the same as the associated experiment 2 described above. However, here the value of Z will be provided, i.e., $Z = 329 \times 10^{-9}$ kg/coulumb. The experiment will provide W and t. Hence,

$$C = \frac{W}{Zt} \text{ amperes, where } W \text{ is in kg.}$$

If the deposition of copper over the cathode plate takes place for $t = 30$ minutes $= 1800$ seconds,

$$C = \frac{W}{329 \times 10^{-9} \times 1800} = \frac{W}{0{\cdot}5922} \text{ amperes.}$$

The voltameter thus provides the measurement of current flowing through it. If the reading of the current by the ammeter be C', then percentage difference between C' and C will be $\frac{C' - C}{C'} \times 100$. This percentage difference is a measure of the correctness of the ammeter.

The experiment may be repeated for different currents and a calibration curve with measured currents against the ammeter readings may be plotted.

4. To determine the value of B.

Hint. Determine k experimentally (Expt. No. 3). Measure the mean diameter d of the coils of the tangent galvanometer, and note the number of turns n of the coils. Then calculate B by the relation

$$B = \frac{\mu_0 n k}{d} \text{ Tesla.}$$

5. To check the correctness of any graduation of the given voltmeter using a voltameter and a standard resistance.

Hints. This experiment will be exactly the same as associated with Expt. 2, provided the given standard resistance is connected in series in the circuit and the voltameter is connected in parallel with the standard resistance. The current C through the voltameter and the standard resistance will be given by

$$C=\frac{W}{Zt}=\frac{W}{329\times10^{9-}\times t}$$ amperes, where W is in kg.

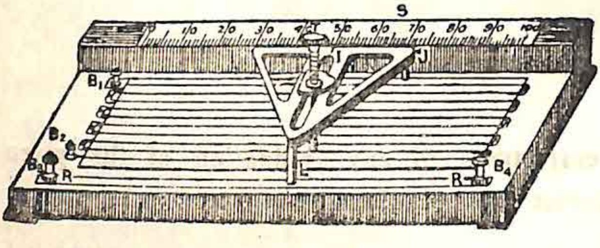
$\therefore$ The p.d. across the standard resistance will be $V=\frac{W\times R}{329\times10^{-9}\times t}$, where R is the value of the standard resistance.

If reading of this p.d. by the voltameter be V', then the percentage difference between V' and V will be $\frac{V'-V}{V'}\times100$ which will be a measure of the correctness of the voltmeter.

EXPERIMENT 4. To compare the e. m. fs. of two cells by a stretched wire potentiometer.

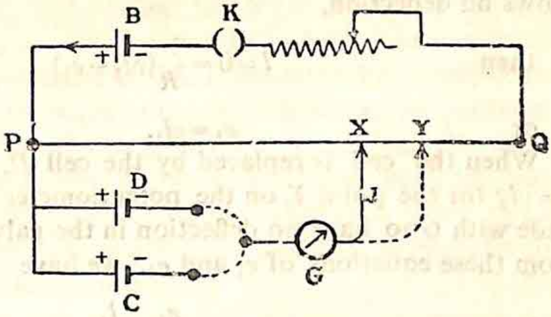
Apparatus. Potentiometer (at least four wires type), a Leclanche cell and a Daniell cell for comparison, two accumulators of 2 volts each, a low resistance suspended coil galvanometer with lamp and scale arrangement, a two-way (or four-way) key, a plug key, two resistance boxes (one of 0—20,000Ω and the other of 0—100Ω), and a rheostat (0—10Ω range).

Description of the Apparatus. POTENTIOMETER : It consists of a wooden board having 4 or 10 wires of uniform diameter, each one metre long, stretched parallel to one another. These wires are soldered together in series on thick plates of copper. The material of wire is selected to have high specific resistance and low temperature coefficient of resistance. Usually the material used is manganin. There are two connecting screws fixed at the end of the first and the last wires. A plate of brass having two connecting screws is arranged parallel to the last wire. A jockey can make contact with this plate and any point on the wire. The point on the wire where contact is made by the jockey is noted on the scale fixed over the wooden board.



(Fig. 6.16)

Theory. Let PQ be a wire of uniform diameter through which a battery B sends a current of C amperes.



(Fig. 6.17)

C and D are two cells whose e.m.fs. e_1 and e_2 are to be compared. The positive poles of these cells and the battery B are connected together to the end P of the wire. C and D can be separately connected to one terminal of the galvanometer G and the other terminal of the galvanometer is connected to a jockey J. Let the cell C be first connected to the galvanometer, and let the battery B be out of circuit. The current starting from the positive pole of the cell C will flow in the galvanometer G in the direction XGC. Next, let the battery B be connected in the circuit. The current starting from the positive pole of the battery B will flow in the galvanometer in the direction CGX which is opposite to that in the former case. The potential difference between P and X arising due to the current from the battery B will be ρl_1 where $\rho =$ potential drop per unit length of the potentiometer wire and $l_1 = PX$. Due to this p.d. current I_1 through G in the direction CGX is

$$I_1 = \frac{\rho l_1}{\text{Resistance in the path } CGX} = \frac{\rho l_1}{R}.$$

Current I_2 flowing through G in the same path, but in opposite direction due to the cell C alone will be

$$I_2 = \frac{\text{Difference of potentials at the ends of the path } XGC}{\text{Resistance of the same path}}$$

$$= \text{e.m.f. of the cell/Resistance of the same path} = \frac{e_1}{R}.$$

When I_1 and I_2 are both flowing through G, total current through G is

$$I = I_1 - I_2 = \frac{1}{R}(\rho l_1 - e_1).$$

If the position of the point X is so adjusted that the galvanometer shows no deflection,

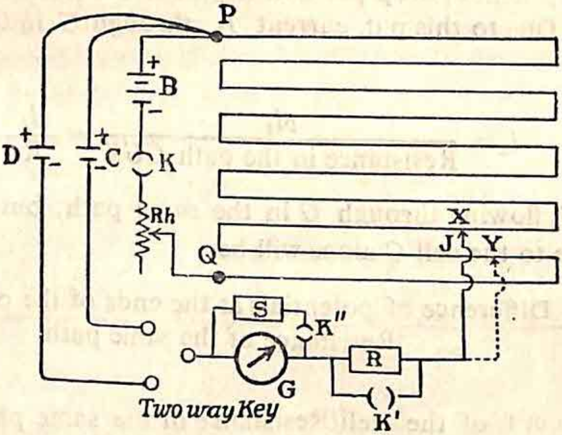
then $$I=0=\frac{1}{R}(\rho l_1-e_1)$$

or $$e_1=\rho l_1.$$

When the cell is replaced by the cell D, we have the equation $e_2=\rho l_2$ for the point Y on the potentiometer where the connection is made with G to have no deflection in the galvanometer. Here $l_2=\rho Y$. From these equations of e_1 and e_2, we have

$$\frac{e_1}{e_2}=\frac{l_1}{l_2}.$$

Procedure. (i) Connect the positive poles of the battery B, the Daniell cell C and the Leclanche cell D to the end P of the potentiometer. After that connect the negative pole of the battery to the key K and the rheostat Rh. The other end of the potentiometer should be connected to the terminal containing the sliding contact of the rheostat. Connect the negative poles of the cells to be compared to the two screws on one side of the two-way key. The third screw of the key should be connected to the galvanometer. Connect the other terminal of the galvanometer to a resistance box R in series. A resistance box may be put in parallel to the galvanometer to provide a shunt to it, and a key K' may be put in parallel to the resistance box R to facilitate exclusion or inclusion of the resistance in the circuit. Finally connect the jockey to the resistance box R.



(Fig. 6.18)

(ii) Put resistance of about 10,000 Ω in the resistance box R, and a resistance of 1 Ω in the shunt S.

(iii) Plug in the key K, and connect the cell C in the circuit with the help of the two-way key. Now press the jockey J and note the direction in which the galvanometer coil is deflected by noticing the movement of the spot on the scale of the lamp and scale arrangement of the galvanometer. When the length of the wire on one side of the jockey is small, the galvanometer deflection will be on one side, and when it is large, the deflection will be on the other side. Pressing the jockey lightly, move it over the wire until a position is reached for which the galvanometer deflection is zero.

(iv) Now reduce the resistance in the resistance box to 1000Ω and adjust the jockey further to find a position for which the deflection is zero. After that plug in the key K' and adjust the jockey further to find a position for which the galvanometer deflection is zero. Finally plug out the key K'' placed in series with shunt S to remove the shunt, and make the final adjustment of the jockey to find a position for which the galvanometer deflection is zero. Now read the length l_1 of the wire from P to X, where the jockey has been finally positioned.

(v) Remove the cell C from the circuit and bring the cell D in the circuit with the help of the two-way key, and find the length l_2 of the wire at which the galvanometer deflection is zero by the same procedure as has been described above.

(vi) Repeat the determination of l_1 and l_2 at least thrice one after another, and find the mean values of l_1 and l_2. Enter your observations in a table as shown below.

Observations and Results

No. of observations	Cell C (e.m.f. e_1)		Cell D (e.m.f. e_2)		$e_1/e_2 = l_1/l_2$
	Position of balance	Mean l_1	Position of balance	Mean l_2	
1					
2					
3					

Note. (i) The system becomes more and more sensitive as the resistance in the resistance box R is gradually diminished. The presence of resistance in the circuit of the cell is necessary to prevent large current to be drawn from the cell and to minimise its polarisation. However, as the current diminishes, the resistance in the circuit of the cell must be decreased to increase the sensitivity of the system.

(ii) If the position of balance is not obtainable, i.e., a one-sided galvanometer deflection is observed for all positions of the jockey, then, provided no mistake has been made in circuit connection, the P. D. between P and Q is less than the e.m.f. of the cell under test. In that case the number of accumulators in the battery B must be increased.

(iii) The rheostat used in series with the battery must be one of low value (about 10 Ω). With such a rheostat, the current in the potentiometer wire will be sufficient to give sufficient p.d. between the ends of the wire, not less than the values of e_1 and e_2. However, its choice is also governed by the fact that l_1 and l_2 should be large to make the percentage error in the result small.

ASSOCIATED EXPERIMENTS

1. To measure the e.m.f. of a cell by a potentiometer.

If one of the cells, say cell D, in Expt. No. 4 is the standard cadmium cell whose e.m.f. e_2 at the room temperature is known, then the e.m.f. of the other cell, say cell C, is given by

$$e_1=\frac{l_1}{l_2}e_2.$$

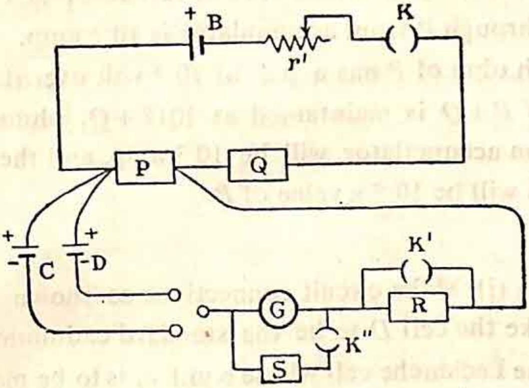
This experiment thus becomes exactly similar to Expt. No. 4 provided the cell C is the cell whose e.m.f. is to be determined and the cell D is the standard cadmium cell.

In fact any p.d. can be compared with the e.m.f. of a standard cell by this process.

EXPERIMENT 5. To determine the e.m.f. of a cell or to measure a p.d. by Rayleigh's potentiometer.

Apparatus. Two post office boxes, an accumulator, standard cadmium cell, Leclanche cell, a resistance box of 0-20,000 Ω range, two resistance boxes of 0-10000 Ω range, three plug keys, a low resistance suspended coil galvanometer with lamp and scale arrangement, a two-way key, and a rheostat.

Theory. In the Rayleigh's potentiometer the wires of a stretched wire potentiometer are replaced by two post office boxes P, and Q in series. The total resistance in P and Q boxes is maintained at a constant value, so that if any resistance is included in P, the same resistance is excluded from Q. A constant current is thus maintained in P and Q from the accumulator.



(Fig. 6.19)

When the cell C of e.m.f. e_1 is in the circuit and the galvanometer deflection is zero for, say, $P=P_1$ and $Q=Q_1$, then in that case, the p.d. across $P_1=\dfrac{eP_1}{P_1+Q_1+r+r'}=e_1$, where e is the e.m.f. of the accumulator B, r = internal resistance of the accumulator, and r' is the resistance in the rheostat.

When the cell D of e.m.f. e_2 is in the circuit, and the galvanometer deflection is zero for, say, $P=P_2$ and $Q=Q_2$, then in that case,

the p.d. across $P_2=\dfrac{eP_2}{P_2+Q_2+r+r'}=e_2$.

Since the equality of P_1+Q_1 and P_2+Q_2 is maintained by proper adjustements in P and Q,

we have from the above equations, $\dfrac{e_1}{e_2}=\dfrac{P_1}{P_2}$.

To make the potentiometer direct reading, the cell D is the standard cadmium cell of e.m.f. 1·018 volts at 26°C. If we take out a resistance of $1000 \times 1{\cdot}018 = 1018$ from P, and a resistance of 1000 from Q, we, then, have $P+Q=2018\ \Omega$. Now, let the standard cell be brought into circuit, and Q be adjusted to a value Q_1 to give zero galvanometer deflection. Now the value of $P+Q=1018+Q_1$. In this condition the p.d. across 1018 Ω resistance is 1·018 volts, so that current through P from accumulator is 10^{-3} amp. In this state of affairs, each ohm of P has a p.d. of 10^{-3} volt over it. So long as the value of $P+Q$ is maintained at $1018+Q_1$ ohms, the current through P from accumulator will be 10^{-3} amp. and the p.d. across P thus produced will be $10^{-3} \times$ value of P.

Procedure. (i) Make circuit connections as shown in the circuit diagram. Take the cell D to be the standard cadmium cell, and the cell C to be the Leclanche cell whose e.m.f. e, is to be measured. Take out 1018 Ω from P and about 1000 Ω from Q. Now bring the cell D into circuit by using the two-way key, and adjust Q to make the galvanometer deflection zero. The sensitivity of the system should be increased by gradually decreasing the resistance in the box R, and increasing the shunt S as advised in Expt. No. 4, to find the accurate value of resistance in Q which makes the galvanometer deflection zero. Note the value of Q; say it is Q_1.

(ii) Now, bring the cell C into circuit and remove the cell D out of circuit by using the two-way key. Keeping $P+Q$ constant to the value $1018+Q_1$ ohms, adjust P and Q till the galvanometer deflection is zero. The sensitivity of the arrangement should be again increased by gradually decreasing the resistance in the box R, and increasing the shunt S as advised in Expt. No. 3, to find the accurate value of the resistance in P which makes the galvanometer deflection zero. Note this value of P; say it is P_2. The e.m.f. of the cell C will be $10^{-3} \times P_2$ volts.

Observation and Results

Adjustment with Standard cell				Adjustment with Leclanche cell			E. m. f. of Leclanche cell
P	Q	Sense of deflection	$P+Q$	P	Q	Sense of deflection	
1018	1000	Left		2000	31	Left	
	1050	Right		1500	531	Left	
	1020	Right		1400	631	Right	
	1010	Left		1450	581	Right	1482×10^{-3} $=1{\cdot}482$ volts.
	1012	Left		1475	556	Right	
	1013	No deflection	2031	1480	551	Right	
				1485	546	Left	
	1014	Right		1484	547	Left	
				1483	548	Left	
				1482	549	No deflection	
				1481	550	Right	

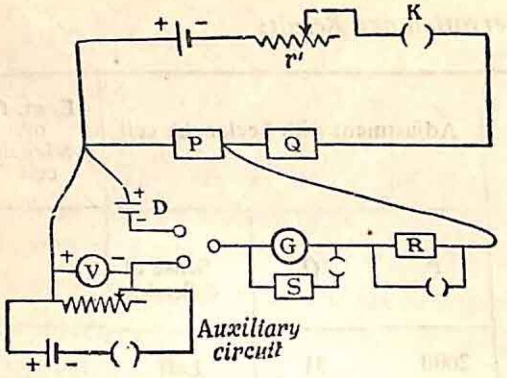
Note. If the exact no-deflection position of galvanometer is not obtainable, find the value of P for which a minimum deflection of galvanometer is observed.

This potentiometer is most suitable to compare any p.d. with the e.m.f. of a standard cell.

ASSOCIATED EXEPRIMENTS

1. To calibrate a voltmeter using a potentiometer.

Hints. The circuit arrangement remains the same as that of Expt. No. 5, except that the Leclanche cell C is replaced by the auxiliary circuit as shown in the figure. The voltmeter is put across the rheostat of the auxiliary circuit, and the p.d. developed across the rheostat and indicated by the voltmeter is applied between the



(Fig. 6.20)

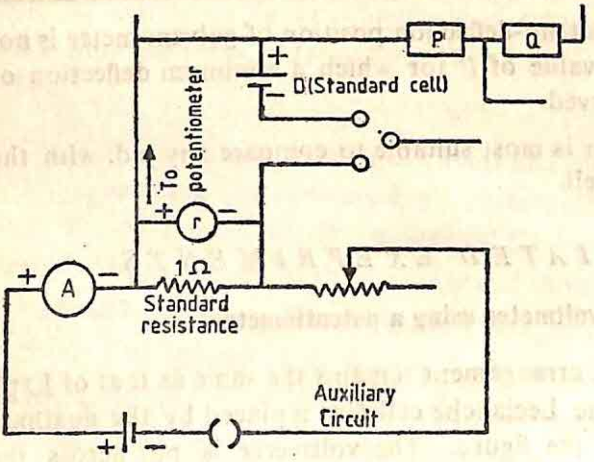
terminals of the box P through the galvanometer, P is then adjusted to get zero deflection of the galvanometer. If the value of resistance in the box P in this condition be P_2, the p.d. applied will be $P_2 \times 10^{-3}$ volts. It must be remembered that the potentiometer is made direct reading following the procedure explained in experiment No. 5.

The reading of the voltmeter is thus checked against the value of p.d. measured. Many such readings may be checked and a calibration curve plotted with measured p.d. against voltmeter readings.

Note. This expt. may be performed with a stretched wire potentiometer also.

2. To calibrate an ammeter using a potentiometer.

Hints. The circuit arrangements remain the same as that of Expt. No. 5 except that the Leclanche cell C is replaced by an auxiliary circuit as shown in Fig. 6.21.



(Fig. 6.21)

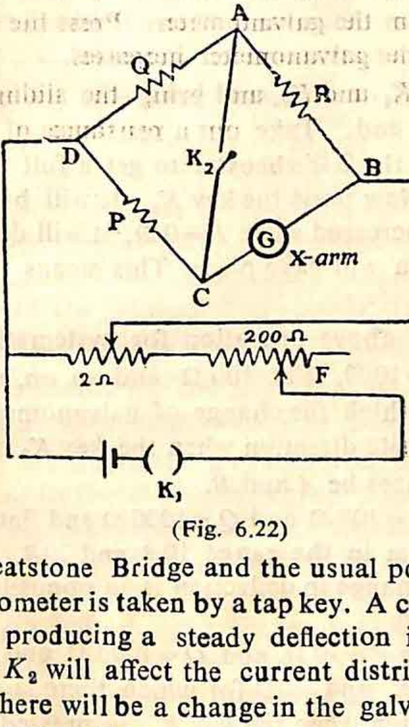
The p.d. developed across the standard 1 Ω resistance is applied between the terminals of the P.O. Box P through the galvanometer. P is then adjusted to get zero deflection of the galvanometer. If the value of the resistance in box P in this condition be P_2, then the voltage across the 1 Ω resistance is $P_2 \times 10^{-3}$ volts, and the current through it is $P_2 \times 10^{-3}/1 = P_2 \times 10^{-3}$ amp. This checks the reading of the ammeter A. Many such readings may be checked and a calibration curve plotted with current through the 1Ω resistance against ammeter readings.

Note. This expt. may be performed with a stretch wire potentiometer also.

EXPERIMENT 6. To determine the resistance of a suspended coil galvanometer by Thomson's (or Kelvin's) method.

Apparatus. A P. O. box, the galvanometer whose resistance is to be measured together with lamp and scale arrangement, Leclanche cell, one rheostat of 200 Ω and another of 2 Ω, and a tap key.

Theory. This method does not require an extra galvanometer to be used as a detector of current. The galvanometer is put in the X-arm of a Wheatstone Bridge and the usual position of the current detecting galvanometer is taken by a tap key. A constant current flows in the net-work producing a steady deflection in the galvanometer. Closing the key K_2 will affect the current distribution in the circuit in general and there will be a change in the galvanometer deflection. However, when $P/Q = G/R$, the points A and C are at the same potential and no current will flow along AC when the key K_2 is closed. Thus in this condition closing the key K_2 will not affect the current distribution in the circuit, and hence the galvanometer deflection will remain unchanged whether the key K_2 is closed or not. It is, therefore, evident that keeping P and Q fixed, R should be adjusted to



(Fig. 6.22)

such a value that closing of K_2 does not change the galvanometer deflection. In that condition,

$$P/Q = G/R$$

or

$$G = P/Q \times R.$$

Procedure. (i) Make circuit connections as shown in the figure given above, putting the galvanometer under test in the X-arm of the Wheatstone Bridge (P. O. Box).

(ii) Put 100 Ω resistance in each of the P and Q arms, and no resistance in R arm of the bridge. Bring the sliding contact of the 2 Ω rheostat to its left end, and bring the sliding contact of the 200 Ω resistance at its end F. In this condition if the key K_1 is closed, practically no p.d. will appear across D and B. Now, close the key K_1, and adjust the 200 Ω rheostat and the 2 Ω rheostat to get a full scale deflection or at least 50 cm in the light spot on the scale of the lamp and scale arrangement when the scale is placed at a distance of about one metre from the galvanometer. Press the tap key and note if the deflection in the galvanometer increases.

(iii) Now open K_1 and K_2, and bring the sliding contact of 2 Ω rheostat again at its end. Take out a resistance of 4000 Ω from R. Close K_1 and adjust the 2 Ω rheostat to get a full scale deflection of the galvanometer. Now press the key K_2. It will be observed that if the deflection had increased when $R = 0$ Ω, it will decrease when $R =$ 4000 Ω, or vice-versa will take place. This means that G is between 0 and 4000 Ω.

(iv) Repeat the above operation for systematically decreasing value of R, say $R = 1000$, 500, 100 Ω and so on, until two values of R are found for which the change of galvanometer deflection is found to be in opposite direction when the key K_2 is pressed.

Let these resistances be A and B.

(v) Now make $P = 100$ Ω and $Q = 1000$ Ω and find two resistances C and D in the R-arm in the range $10A$ and $10B$, differing by one ohm for which the change in deflection is in opposite direction when the key K_2 is pressed.

(vi) Finally make $P = 10$ Ω, and $Q = 1000$ Ω and find a resistance E in the range $10C$ and $10D$ for which there is no change in the galvanometer deflection when the key K_2 is pressed. The value of G will be given by

$$G = \frac{E}{100}\,\Omega.$$

Observations and Results

P Ω	Q Ω	P/Q	R Ω	Change in Deflection in galvanometer	Conclusion about G
100	100	1	0	Increased	$G > 0\ \Omega$
			4000	Decreased	$G < 4000\ \Omega$
			1000	Decreased	$G < 1000\ \Omega$
			500	Decreased	$G < 500\ \Omega$
			100	Decreased	$G < 100\ \Omega$
			50	Decreased	$G < 50\ \Omega$
			40	Increased	$G > 40\ \Omega$
			45	Decreased	$G < 45\ \Omega$
			44	Increased	$G > 44\ \Omega$
100	1000	$\frac{1}{10}$	450	Decreased	$G < 45{\cdot}0\ \Omega$
			440	Increased	$G > 44{\cdot}0\ \Omega$
			445	Decreased	$G < 44{\cdot}5\ \Omega$
			444	Increased	$G > 44{\cdot}4\ \Omega$
10	1000	$\frac{1}{100}$	4450	Decreased	$G < 44{\cdot}50\ \Omega$
			4440	Increased	$G > 44{\cdot}40\ \Omega$
			4441	No change	Mean
			4442	No change	$R = 4442{\cdot}5\ \Omega$
			4443	No change	$\therefore\ G = 44{\cdot}425\ \Omega$
			4444	No change	
			4445	Decreased	$G < 44{\cdot}45\ \Omega$

Resistance of the galvanometer $= 44{\cdot}425\ \Omega$.

Notes. (i) This method does not provide as accurate a result as is provided by clamping the galvanometer coil and measuring its resistance by the usual method of P.O. Box (Wheatstone Bridge).

(ii) As the change in the galvanometer deflection due to change in the resistance in the R branch is proportional to the galvanometer deflection, a large deflection of the galvanometer is necessary for better accuracy in the determination of G. In case, the effort to have a large deflection of the galvanometer results in the light spot on the scale going beyond its end, the torsion head of the galvanometer should be rotated to bring the spot on the end of the scale. Effort must be made to have large galvanometer deflection for the success of the experiment.

EXPERIMENT 7. **To determine the resistance of a suspended coil galvanometer by half deflection method.**

Apparatus. The suspended coil galvanometer with lamp and scale arrangement, a commutator, a resistance box of 0—20,000Ω range,

P. O. box, a rheostat of 2 Ω, an accumulator and a key.

Theory. Referring to the circuit diagram given below, let r be the resistance from the 2 Ω rheostat placed in parallel to G and R in series. The equivalent resistance across the points A and B of the circuit is $\frac{r(G+R)}{G+R+r}$. The main current I flowing through this resistance produces a p. d. across AB equal to $\frac{r(G+R)}{G+R+r}I$. The current I_g through the galvanometer will be given by

$$I_g=\frac{r}{G+R+r}I.$$

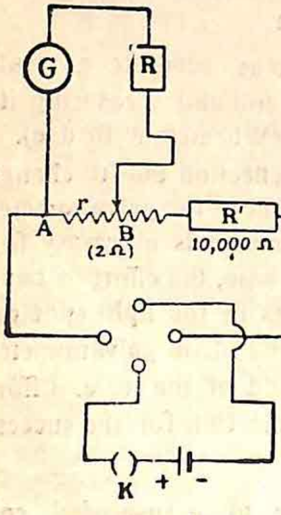
This current produces a deflection d of the light spot. So

$$I_g=kd=\frac{r}{G+R+r}I.$$

Let the deflection be d_1 when $R=0$, so that

$$\frac{r}{G+r}=kd_1 \qquad \ldots \quad (1).$$

Now, when $R=R$, let the deflection d_2 be $\frac{d_1}{2}$ so that



(Fig. 6.23)

$$\frac{r}{G+R+r}=k\frac{d_1}{2} \qquad \ldots \quad (2).$$

∴ From equations (2) and (1)

$$\frac{G+R+r}{G+r}=2$$

or $$G+R+r=2G+2r$$

∴ $$G=R-r.$$

If r is negligibly small compared to R,

$$G=R.$$

Procedure. (i) Make circuit connection as shown in the circuit diagram. Make $R=0$, and remove the sliding contact of the 2Ω resistance to its end A. Make $R'=10{,}000$Ω.

(ii) Now close the key K and the commutator keys suitably, and adjust the sliding contact of the 2Ω rheostat to obtain a deflection of 20 cm of the light spot from the galvanometer. Note this deflection.

Reverse the direction of current using the commutator and note the deflection again. Find the mean deflection d_1.

(iii) Now gradually adjust the resistance R until for two values of R differing by 1 ohm, the deflection of the light spot is nearly $\frac{d_1}{2}$. Let these values of R be p and $p+1$. Let the deflection for $R=p$ be m and that for $R=p+1$ be n. Therefore, the value of R which makes the deflection exactly equal to $\frac{d_1}{2}$ will be given by

$$R=p+\frac{m-d_1/2}{m-n}.$$

In practice this value of R is quite large compared to r, so that

$$G=p+\frac{m-d_1/2}{m-n}.$$

(iv) Repeat the above procedure at least three times for different values of d_1, say $d_1=20$, 18 and 16 cm and find the value of G in every case. Finally obtain the mean value of G.

Note. Take care to ensure that r in the experiment does not exceed $\frac{1}{10}$ of the total resistance of the rheostat used. Only then the value of G will be obtained with good accuracy.

Observations

No. of observation	Deflection d_1 in cm for $R=0\ \Omega$			R in Ω	Deflection in cm			Conclusion about deflection
	Direct	Reversed	Mean		Direct	Reversed	Mean	
1	21·5	20·7	21·1	10	18·2	17·8	18·0	More than half
				20	14·4	13·8	14·2	More than half
				30	12·3	12·1	12·2	More than half
				35	11·1	11·0	11·05	More than half
				36	10·7	10·6	10·65	More than half
				37	10·2	10·0	10·1	Less than half
2								
3								

Calculations and Results

$$G \text{ from observation No. } 1 = 36 + \frac{10{\cdot}65 - 10{\cdot}55}{0{\cdot}55} = 36{\cdot}2\ \Omega$$

G from observation No. 2 = ...

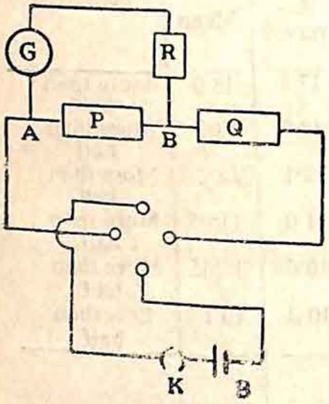
G from observation No. 3 = ...

Mean value of G = ...

EXPERIMENT 8. To determine the figure of merit of a suspended coil galvanometer, and the constant of a Ballistic galvanometer by figure of merit method.

Apparatus. The suspended coil galvanometer of known resistance with lamp and scale arrangement, commutator, an accumulator, and three resistance boxes : the first of 0— 0Ω, the second of 0—5000Ω, and the third of 0—50000Ω.

Theory. The figure of merit of a suspended coil galvanometer having a lamp and scale arrangement is measured by the current in amperes which flowing through the galvanometer coil produces a deflection of 1 mm of the light spot on a scale placed parallel to the coil of the galvanometer at a distance of 1 metre. A circuit arrangement of the type shown below may be used to determine the figure of merit of a galvanometer.



(Fig. 6.24)

The equivalent resistance across the points A and B in the circuit

$$= \frac{P(R+G)}{P+R+G}.$$

If B be the internal resistance of the accumulator in the circuit, and E be its e.m.f., the current I drawn from the battery is given by

$$I = \frac{E}{\dfrac{P(R+G)}{P+R+G} + Q + B}$$

$$= \frac{E(P+R+G)}{P(R+G)+(Q+B)(P+R+G)}.$$

$\therefore$ The current I_g through the galvanometer is given by

$$I_g = \frac{PI}{G+R} = \frac{EP(P+R+G)}{P(R+G)^2+(Q+B)(G+R)(P+R+G)}$$

$$=\frac{EP}{(Q+B)(G+R)+\dfrac{P(R+G)^2}{(P+R+G)}}.$$

If B is negligibly small compared to Q, and also P is very small compared to $R+G$, we may write

$$Q+B \text{ approximately} = Q$$

and $$P+R+G \text{ approximately} = R+G.$$

$$\text{Hence } I_g=\frac{EP}{Q(G+R)+P(G+R)}$$

$$=\frac{EP}{(P+Q)(G+R)}.$$

If $P+Q$ is made thousand times the value of E, then

$$I_g=\frac{P}{1000(G+R)} \text{ amperes}$$

$$=\frac{P}{G+R}\times 10^{-3} \text{ amperes} \quad .. \quad (1).$$

If this current flowing through the galvanometer coil deflects the light spot by S' mm on the scale placed at a distance of d cm from the coil, then the deflection S mm of the spot when the scale is placed at 100 cm from the coil will be given by

$$\frac{S}{S'}=\frac{100}{d}, \text{ or } S=\frac{100}{d}S' \quad .. \quad (2).$$

Therefore, the figure of merit of the galvanometer will be

$$\frac{I_g}{S}=\frac{I_g}{S'}\cdot\frac{100}{d} \text{ amp./mm} \quad .. \quad (3).$$

If G be a Ballistic galvanometer, its constant $K=\frac{T}{2\pi}\cdot\frac{C}{nAH}$, where T sec is the time period of torsional oscillations of the galvanometer coil. Further as $I_g=\left(\frac{C}{nAB}\right)\frac{1\cdot 1}{100}$,

$$K=\frac{T}{2\pi}\quad\frac{C}{nAB}=\frac{T}{2\pi}\cdot 1000\ I_g/S. \text{ coulumbs/radian.}$$

Procedure. (i) Arrange the scale and lamp properly at about 100 cm from the galvanometer coil, and focus the lamp to obtain a sharp light spot due to the beam of light reflected from the mirror attached to the suspension of the galvanometer coil. Place the centre of the spot on the zero mark of the scale. Measure the distance between the scale and the coil in cm with the help of a metre scale.

(ii) Now make circuit connections as shown in the circuit diagram. Measure the e.m.f. E of the accumulator with the help of a voltmeter. Let it be n volts. Make $P=1\Omega$ and take out the resistance from Q which makes $P+Q=1000n$. Take out 15000Ω from R. Now, close the key K, and the commutator keys properly. Observe the deflection in the galvanometer and if the value of S' is not less than 20 mm and more than 1000 mm, note the deflection. Reverse the direction of the current through P and Q and note the deflection again. Find the mean of the two deflection readings, and use it to calculate the figure of merit.

Note. If S' is less than 20 mm, increase the value of P. This will increase S'. If S' be more than 1000 mm, increase the value of R. This will decrease S'. For a very sensitive galvanometer R may have to be of the order of a fraction of a megohm. In that case a megohm box should be used in the position of R.

(iii) Note the deflections in the galvanometer for direct and reversed currents keeping $P=2\Omega$, $3\ \Omega$,.., $10\ \Omega$ taking care to make $P+Q=1000n$ all the time. Calculate the value of figure of merit in every case. Finally, calculate the mean value of the figure of merit.

Observations and Calculations

E M F. of the accumulator used $=n=2{\cdot}0$ volts.
$R=15000\ \Omega$, $G=35{\cdot}0\ \Omega$ (as in expt. no. 7)
$P+Q=1000\,n=2000\ \Omega$.

The distance between galvanometer coil and the scale $=d=97{\cdot}0$ cm.

No. of observation	P in Ω	Q in Ω	Deflection S' in mm			I_g in amp.	Figure of merit in amp/mm	Mean Figure of merit
			Direct current	Reversed current	Mean S'			
1	1	1999	21	23	22	$6{\cdot}67\times10^{-8}$	$3{\cdot}12\times10^{-9}$	
2	2	1998						
3	3	1997						
⋮								
10	10							

Graph. Draw a graph with P on x-axis and deflection S' on y-axis. The graph should be a straight line, as

$$I_g = \frac{P}{G+R} \times 10^{-3} = KS'$$

where K is a constant.

Here G and R being constant

$$S' \propto P.$$

From the graph obtain the value of S' for any chosen value of P. Calculate S from this value of S' using equation (2) and I_g from the chosen value of P using equation (1). Then calculate the figure of merit by dividing I_g by S.

Results.

Mean value of figure of merit by calculations = ...

Value of figure of merit by the use of the graph= ......

If G is a *B.G.* also calculate K by determining T with the help of the stop-watch, and calculate the constant K of the *B.G.*

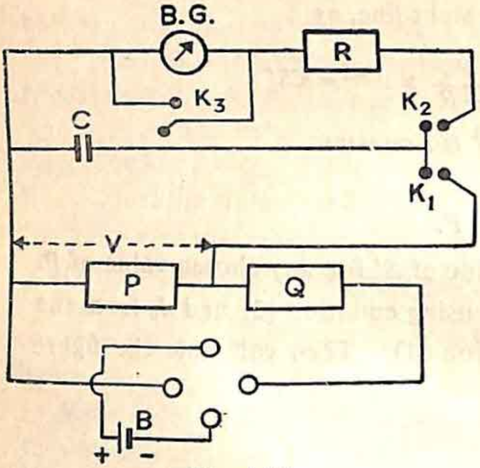
Note. (i) If the resistance of the galvanometer is not given, the same circuit may be used to determine the resistance of the galvanometer by half deflection method.

(ii) If G be small compared to R, I_g may be calculated by neglecting the value of G, i.e., when G is negligible compared to R,

$$I_q = \frac{P}{R} \times 10^{-3} \text{ Ampere.}$$

EXPERIMENT 9. **To determine the constant of a suspended coil ballistic galvanometer by charge and discharge of a condenser.**

Apparatus. The suspended coil ballistic galvanometer with lamp and scale arrangement, a resistance box of 0—1000 Ω, a standard condenser of 4 micro-farad, a four-poles commutator, two tap keys, a storage cell, a voltmeter, and two resistance boxes : one of fraction ohms (P) and the other of 0—100,000 Ω (Q).



(Fig. 6.25)

Theory. Referring to the circuit diagram shown beside, by pressing the key K_1, the condenser of capacity C is charged. The charge Q on the condenser is given by $Q=CV$, where V is the p.d. applied. If K_1 is opened and the key K_2 pressed, this charge is quickly sent through the ballistic galvanometer and a throw is noticed in the coil of the galvanometer. Let the first throw be θ_1 then,

$$Q=CV=K\theta\ (1+\lambda/2)$$

where K is a constant called the Ballistic constant, and λ is another constant, called the logarithmic decrement of the galvanometer whose value depends upon the resistance of the galvanometer and the resistance R in its circuit.

From the above equation, $K=\dfrac{CV}{\theta_1(1+\lambda/2)}$.

If the light spot reflected from the galvanometer mirror and received on a scale placed at D cm be deflected by d_1 cm due to the throw of the coil, then

$$\theta_1=\frac{d_1}{2D}$$

so that $K=\dfrac{2CVD}{d_1(1+\lambda/2)}$. Here $V=\dfrac{\text{p.d. cross } B}{P+Q}\cdot P$.

C, V, D and d_1 are easily measurable quantities. Hence if λ is determined with the value of R to be used in the experiment, then K can be calculated.

To determine λ, let the coil of the galvanometer execute torsional oscillations after a charge Q has been passed suddenly through it, and while it oscillates let the spot of the light be deflected successively by $d_1, d_2, d_3 \ldots d_{10}$ on the same side as the coil is thrown successively by $\theta_1, \theta_2, \theta_3 \ldots \theta_{10}$ respectively. Then

$$\frac{\theta_1}{\theta_2}=\frac{d_1}{d_2}=\frac{\theta_2}{\theta_3}=\frac{d_2}{d_3}=\ldots\ldots=p^2=\text{a constant.}$$

$$\log_e p = \lambda, \text{ so that } \log_e p^2 = 2 \log_e p = 2\lambda$$

or $$\log_e \frac{d_1}{d_2} = 2\lambda.$$

Further, $$\frac{d_1}{d_6} = \frac{d_1}{d_2} \cdot \frac{d_2}{d_3} \cdot \frac{d_3}{d_4} \cdot \frac{d_4}{d_5} \cdot \frac{d_5}{d_6} = p^{10},$$

$$\therefore \quad \log_e \frac{d_1}{d_6} = \log_e p^{10} = 10 \log_e p = 10\lambda.$$

Similarly, $$\log_e \frac{d_2}{d_7} = 10\lambda,$$

$$\log_e \frac{d_3}{d_8} = 10\lambda, \quad \log_e \frac{d_5}{d_{10}} = 10\lambda.$$

Thus from observation of $d_1, d_2 \,..\, d_{10}$, the mean value of 10λ, and hence the value of λ can be calculated.

Procedure. (i) Arrange the scale and the lamp properly at about 100 cm from the galvanometer coil, and focus the lamp to obtain a sharp light spot on the scale due to the beam of light reflected from the mirror attached to the suspension of the galvanometer. Place the centre of the spot on the zero mark of the scale. Measure the distance D between the scale and the galvanometer coil in cm with the help of a metre scale.

(ii) Take a storage cell, not freshly charged, and make circuit connections as shown in the circuit diagram. Keep a resistance of 1000 Ω in the box R, and after taking a small resistance in P and a large resistance in Q, place the keys in the commutator properly. Close the tap key K_1 for about one minute. Now open K_1 and quickly press K_2 to discharge the condenser through the galvanometer. See if a deflection of about 20 cm is obtained. If the deflection is small or very large, adjust P, Q and R gradually until the deflection on the scale when the condenser is discharged is about 20 cm. While the coil oscillates note the successive deflections $d_1, d_2, d_3, \,..\, d_{10}$ on the same side, and calculate λ.

(iii) An accurate determination of first deflection d_1 is now needed. For this charge the condenser for about one minute by pressing the key K_1. Now open the key K_1 and quickly press K_2. Note the first deflection d_1 of the light spot on the scale. Repeat the processes of charging and discharging at least five times and note the value of d_1 every time. Use the key K_3 to damp down the oscillations of the coil whenever necessary.

(iv) Now reverse the polarity of the charging battery in the circuit by changing the position of the commutator keys properly. Repeat the charging and discharging processes again as described above at least five times, and note the value of d_1 every time.

(v) Find the mean value of d_1.

(vi) Measure the p. d. across the cell B with a high resistance voltmeter.

Observations

E.M F. of the storage battery $= V = \ldots.$volts.
Distance between the galvanometer coil
and the scale $= D = \ldots.$cm. $R = \ldots.$ohm.

Determination of λ.

$d_1 = \ldots\ldots\ldots$
$d_2 = \ldots\ldots\ldots$
$d_3 = \ldots\ldots\ldots$
$d_4 = \ldots\ldots\ldots$
$d_5 = \ldots\ldots\ldots$
$d_6 = \ldots\ldots\ldots$
$d_7 = \ldots\ldots\ldots$
$d_8 = \ldots\ldots\ldots$
$d_9 = \ldots\ldots\ldots$
$d_{10} = \ldots\ldots\ldots$

$\frac{d_n}{d_{n+5}}$	$\log_e \frac{d_n}{d_{n+5}} = 10\lambda$	λ	*Mean* λ

Determination of K.

No. of obser-vations	Deflection d_1 in cm		
	Direct	Reverse	Mean
1			
2			
3			
4			
5			

Calculations and Result

$$K=\frac{2CVD}{d_1(1+\lambda/2)}=\ldots\ldots\ldots\ \frac{\text{Coulomb}}{\text{Radian}}.$$

Note. The voltage for charging of the condenser should be decided by observing the deflection of the light spot when the condenser is discharged through the galvanometer. If the deflection is small, the number of cells of the battery in series may be increased. If necessary a condenser of larger value may also be used.

ASSOCIATED EXPERIMENTS

1. To compare two capacities by using a ballistic galvanometer.

Hints. For this experiment determination of the value of K and λ is not needed. If the two capacities C_1 and C_2 are charged to the same voltage V, the charge on them are

$$Q_1=C_1V \text{ and } Q_2=C_2V.$$

If these capacitances are discharged one after another through a ballistic galvanometer and the first deflections of the light spot on the scale are d_1 and d_1' respectively, then

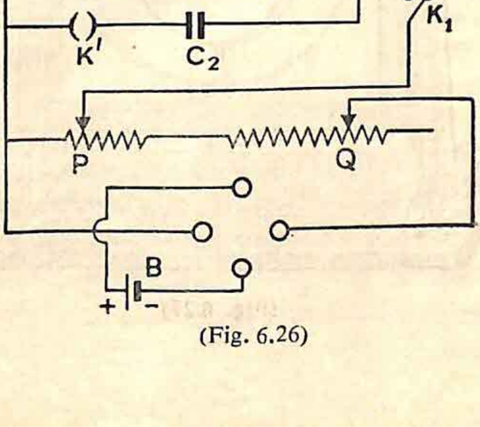
$$Q_1=C_1V=Kd_1(1+\lambda/2)$$

and

$$Q_2=C_2V=Kd_1'(1+\lambda/2)$$

$$\therefore\quad \frac{C_1}{C_2}=\frac{d_1}{d_1'}.$$

The circuit diagram for this experiment will be as shown below.



(Fig. 6.26)

P is a low resistance (2Ω) rheostat and Q is a high resistance rheostat (5000Ω).

K and K' are two plug keys. If the key K is plugged in and K' is plugged out, then C_1 is charged when K_1 is pressed, and discharged when K_1 is opened and K_2 is pressed. Similarly if the key K' is plugged in and K is plugged out, then C_2 is charged when K_1 is pressed and discharged when K_1 is opened and K_2 is pressed.

2. To determine the capacity of a condenser by comparing it with a standard condenser.

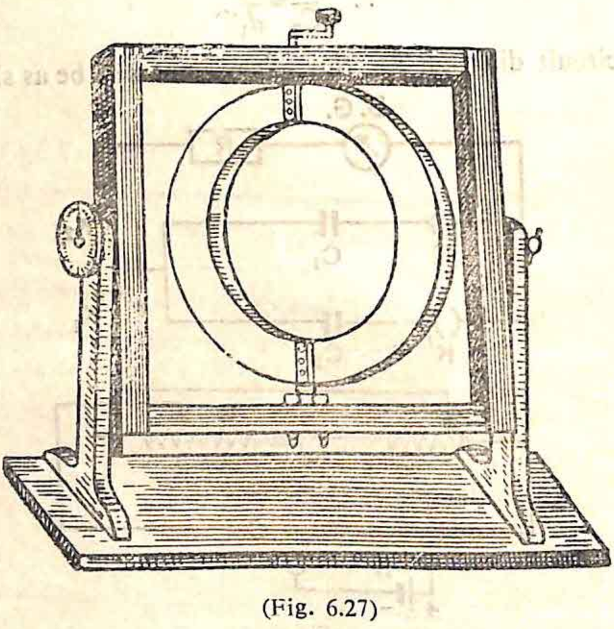
Hints. The same circuit diagram as given above should be used. If C_2 be the standard condenser, then

$$C_1 = \frac{d_1}{d_1'} . C_2.$$

EXPERIMENT 10. To determine the value of δ of the earth's magnetic field by an Earth Inductor.

Apparatus. Earth inductor, a resistance box, a suspended coil ballistic galvanometer with lamp and scale arrangement, a magnetometer box.

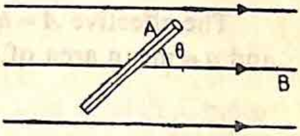
Description of the Apparatus : EARTH INDUCTOR. An Earth Inductor is a circular coil of several turns of wire wound over a circular metallic or wooden frame. The frame can be rotated and is held by a catch in



(Fig. 6.27)

another rectangular fixed frame. A spring arrangement quickly rotates the frame by 180° as soon as the catch is pulled back. The frame may be brought back by hand and held in position by the catch.

The earth inductor may be arranged with the plane of its coil either vertically or horizontally by turning the rectangular frame in which the circular frame is fixed. The ends of the circular coil are connected to two commutators separated from each other and fixed on the axis. Two springs, called the collectors press against the commutators lightly. These are connected to the connecting screws.



(Fig. 6.27 A)

Theory. Let a closed coil of effective area A be situated in a uniform magnetic field B. If the plane of the coil makes an angle θ with the direction of the field, the magnetic flux linked with the coil $= BA\sin\theta = N$.

The rotation of the coil induces an e.m.f. e, at any instant of time t, given by

$$e = -\frac{dN}{dt} = -BA\,\frac{d(\sin\theta)}{dt},$$

and the current i through the coil at that instant is given by

$$i = \frac{e}{r} = -\frac{BA}{r}\,\frac{d(\sin\theta)}{dt},$$

where r = resistance of the closed circuit of the coil,

or $$i\,dt = -\frac{BA}{r}\,d(\sin\theta).$$

If $\theta = \pi/2$ at time $t = 0$, and $-\pi/2$ at the end of an interval of time, i.e., the coil is at right angles to the field before and after the rotation, then the charge Q flown through the coil in this interval is given by

$$Q = \int_0^t i\,dt = -\frac{BA}{r}\int_{\theta=\pi/2}^{\theta=-\pi/2} d(\sin\theta)$$

$$= -\frac{BA}{r}\Big[\sin\theta\Big]_{\pi/2}^{-\pi/2} = \frac{2BA}{r}.$$

If the coil is in series with a ballistic galvanometer,

$Q = k\theta_1(1 + \lambda/2)$,

where k = ballistic constant,

λ = logarithmic decrement of the galvanometer for the given resistance in its circuit,

θ_1 = first throw of the galvanometer coil as the charge suddenly passes through it.

Hence, $$\frac{2BA}{r} = k\theta_1 (1+\lambda/2);$$

$$\therefore \quad B = \frac{rk}{2A}\theta_1(1+\lambda/2).$$

The effective $A = na$, where n = total number of turns of the coil and a = mean area of a turn. Hence

$$B = \frac{rk}{2na}\theta_1(1+\lambda/2) \quad .. \quad (1).$$

If the coil is arranged vertically with its plane at right angles before and after rotation, then B is horizontal component of the earth's field.

If the coil is arranged horizontally with its plane being horizontal before and after the 180° rotation, then the field in which it rotates is the vertical component B' of the earth's field,

and $$B' = \frac{rk}{2na}\theta_1'(1+\lambda/2) \quad .. \quad (2)$$

where θ_1' is the first throw of the galvanometer coil as the charge suddenly passes through it.

Further, since $\tan\delta = \frac{B'}{B}$, δ being the dip,

$$\delta = \tan^{-1}\frac{B'}{B} = \tan^{-1}\frac{\theta_1'}{\theta_1}.$$

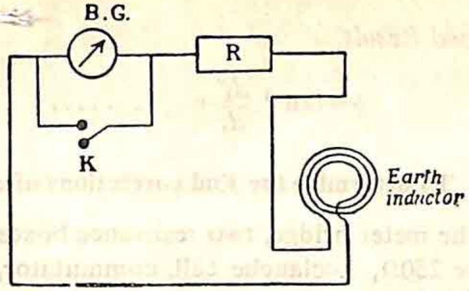
Let the distance between the coil of the galvanometer and the scale of the lamp and scale arrangement be D, and let d_1 and d_1' be the deflections of the light spot on the scale, when the throws of the coil are θ_1 and θ_1' respectively.

Then $$\theta_1 = \frac{d_1}{2D}, \text{ and } \theta_1' = \frac{d_1'}{2D}.$$

Hence, $$\delta = \tan^{-1} d_1'/d_1.$$

Procedure. (i) Make circuit connections as shown in the circuit diagram.

Arrange the scale of the lamp and scale arrangement at a distance of about 100 cm from the galvanometer coil. Focus the lamp to get a sharp spot of light over the scale.



(Fig. 6.28)

(ii) Place a magnetometer box over the table and stretch a piece of thread along its pointer. This gives the direction perpendicular to the magnetic meridian. Now place the frame of the coil of the Earth Inductor under the catch, and rotate the Earth Inductor as a whole to make the coil parallel to the thread stretched. Do not take any resistance in the resistance box R. Withdraw the catch of the Earth Inductor to suddenly rotate the coil by 180°. If the first deflection of the light spot does not go out of the scale, note its value. If it goes out of the scale (normally it would not) then take a proper resistance in the resistance box R, and then repeat the process of getting the first deflection. Repeat this observation at least five times and calculate the mean deflection d_1.

(iii) Now arrange the Earth Inductor such that the frame of its coil when put under the catch is horizontal. A spirit level may be used over the frame of the coil to check if it is horizontal. If it is not so, then wooden wedges may be inserted under the base of the Inductor to make it horizontal. Now withdraw the catch of the Earth Inductor to suddenly rotate the coil by 180°. Note the first deflection of the light spot over the scale. Repeat this observation at least five times, and calculate the mean deflection d_1'.

Observations

No. of obser-vations	Reading of d_1 in cm	Mean d_1 cm	Reading of d_1' in cm	Mean d_1' cm
1				
2				
⋮				
⋮				
5				

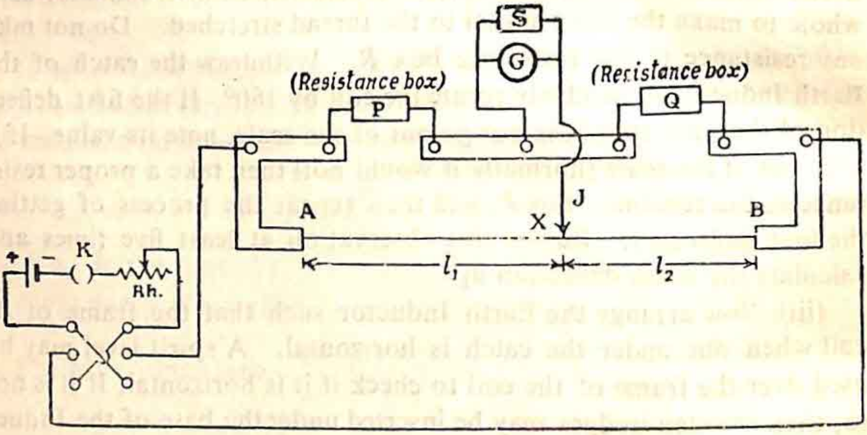
Calculation and Result.

$$\delta = \tan^{-1} \frac{d_1'}{d_1} = \ldots\ldots\ldots$$

EXPERIMENT 11. To determine the End corrections of a Meter bridge.

Apparatus. The meter bridge, two resistance boxes each of 0-200Ω, rheostat of above 250Ω, Leclanche cell, commutator, suspended coil galvanometer with lamp and scale arrangement, a resistance box of 0—50Ω to be used as shunt, and a jockey.

Theory. The wire of the meter bridge is connected to metal pieces at its ends. Normally the resistances of these metal pieces are assumed to be negligible. But when a great accuracy is demanded, correction for the resistances of these pieces must be made. Also the ends of the wire may not be exactly at the zero and hundred marks of the scale fixed by the side of the wire. Hence a correction for this error is also necessary. The total corrections needed for the ends of the bridge wire on account of the resistances of the metal pieces connecting the ends of the bridge wires, and on account of the ends of the bridge wire not being on the 0 and 100 marks of the scale, are called the end corrections.



(Fig. 6.29)

Referring to the above circuit connection with the meter bridge, which is essentially a Wheatsone bridge circuit, let the galvanometer deflection be zero when the jockey makes contact with the meter bridge wire at *X*. Length of the wire as read on the scale on the left of *X* is l_1 and on the right of this point is l_2.

If the resistances on the left and on the right of the ends of the bridge wire be equivalent to length λ_1 and λ_2 respectively of the bridge wire, then, when the bridge balanced,

$$\frac{P}{Q}=\frac{l_1+\lambda_1}{l_2+\lambda_2}.$$

If

$$\frac{P}{Q}=\frac{1}{N},$$

$$\frac{1}{N}=\frac{l_1+\lambda_1}{l_2+\lambda_2}$$

or

$$l_2+\lambda_2=N(l_1+\lambda_1) \quad .. \quad (1).$$

If P, and Q are interchanged in their positions,

$$\frac{Q}{P}=N=\frac{l_1'+\lambda_1}{l_2'+\lambda_2}$$

or

$$l_2'+\lambda_2=\frac{1}{N}(l_1'+\lambda_1) \quad .. \quad (2).$$

From equations (1) and (2)

$$l_2-l_2'=N(l_1+\lambda_1)-\frac{1}{N}(l_1'+\lambda_1)$$

$$=\frac{N^2(l_1+\lambda_1)-(l_1'+\lambda_1)}{N}$$

or

$$N(l_2-l_2')=\lambda_1(N^2-1)+N^2l_1-l_1'$$

$$\therefore \quad \lambda_1=\frac{N(l_2-l_2')-N^2l_1+l_1'}{(N+1)\,(N-1)}.$$

As

$$l_2=100-l_1, \text{ and } l_2'=100-l_1',$$

$$l_2-l_2'=l_1'-l_1;$$

so that,

$$\lambda_1=\frac{N(l_1'-l_1)-N^2l_1+l_1'}{(N+1)\,(N-1)}$$

$$=\frac{(N+1)\,l_1'-Nl_1(N+1)}{(N+1)\,(N-1)}$$

$$=\frac{l_1'-Nl_1}{N-1}.$$

Similarly,

$$\lambda_2=\frac{l_2-Nl_2'}{N-1}$$

For convenience of calculation, N may be easily made, 101,

so that,
$$\lambda_1 = \frac{l_1' - 101 l_1'}{100}$$

and
$$\lambda_2 = \frac{l_2 - 101 l_2'}{100}.$$

Procedure. (i) Make circuit connections as shown in the circuit diagarm. Make the resistance P equal to 1Ω, and the resistance Q equal to 101Ω. Keep the shunt resistance at 1Ω, and put the full resistance of the rheostat in the circuit in the beginning.

(ii) Now close the key K, and shift the jockey towards the left end of the wire. Press the jockey lightly against the bridge wire. If the connections are all right, galvanometer deflection will be on one side of the zero mark of the scale of the lamp and scale arrangement when jockey is at the end of the bridge wire, and on the other side when it is away from the end towards the right of it. Bring the jockey near the point at which the galvanometer deflection tends to be zero. Move the sliding contact of the rheostat to reduce the resistance in the battery circuit and also increase the shunt resistance across the galvanometer. This will increase the sensitivity of the arrangement. Now press the jockey lightly and move it along the wire to a point where the galvanometer deflection becomes zero. Note the length l_1 of the bridge wire on the left of the position indicator of the jockey. The length l_2 on the right of this position will be $100 - l_1$. Reverse the direction of current with the help of the commutator and again find l_1 and l_2.

(iii) Now interchange P and Q in their positions, and shift the jockey near the other end of the bridge wire. Adjust the position of the jockey to obtain zero deflection of the galvanometer, Note the length l_1' of the wire on the left of the position of the jockey. The length l_2' will be $100 - l_1'$. Reverse the direction of the current with the help of the commutator and find l_1' and l_2' again.

(iv) Repeat the above observations with $P = 1\Omega$ and $Q = 91\Omega$ to obtain a second set of readings of l_1, l_2 and l_1', l_2'.

(v) Calculate λ_1 and λ_2 from each of the two sets of readings, and the mean value of λ_1 and λ_2.

Observations

No. of observation	P Ω	Q Ω	l_1 and l_1' in cm			l_2 and l_2' in cm		
			Direct current	Reverse current	Mean	Direct current	Reverse current	Mean
1	1	101	0·61	0·59	0·60	99·39	99·41	99·40
	101	1	99·42	99·40	99·41	0·58	0·60	0·59
2	1	91						
	91	1						

Calculations and Results.

From 1st set, $\lambda_1 = \dfrac{99{\cdot}41 - 101 \times 0{\cdot}60}{100} = 0{\cdot}388$ cm.

$\lambda_2 = \dfrac{99{\cdot}40 - 101 \times 0{\cdot}59}{100} = 0{\cdot}398$ cm.

From 2nd set, $\lambda_1 =$ ....
$\lambda_2 =$ ....
Mean $\lambda_1 =$ ....
and $\lambda_2 =$ ....

ASSOCIATED EXPERIMENTS

1. To determine the resistance of a coil with a bridge applying end corrections.

Hints. First determine the end corrections of the meter bridge wire. Then make the circuit connection as shown in experiment No. 2 and follow the procedure of resistance measurement as described in para (iii) of the procedure section of Expt. No. 2. At least three observations should be taken for three values of resistance in the resistance box P, and mean resistance of the coil should be calculated.

2. To determine the specific resistance of the material of wire by a meter bridge.

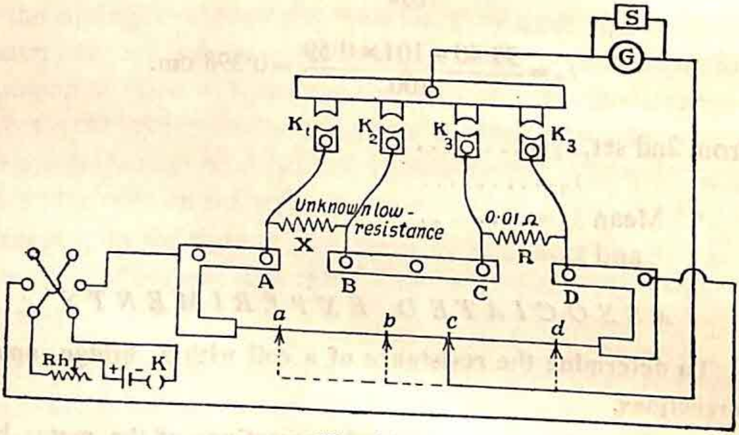
Hints. Determine the resistance X in Ω of the wire with the meter bridge using end corrections. Measure the diameter of the wire using a screw gauge and calculate the area of cross-section, S sq. m of the wire. The procedure adopted for this purpose should be the same as described in a book of Practical Physics for I. Sc. students. Measure the length, l m of the wire by a metre scale. Calculate the specific resistance ρ by the relation,

$$\rho = \frac{XS}{l} \text{ ohm-m.}$$

EXPERIMENT 12. To measure a low resistance (or the resistance of an ammeter) by Mathiessen and Hokin's method

Apparatus. The low resistance (this may be an ammeter), a suspended coil galvanometer with lamp and scale arrangement, a meter bridge, a standard low resistance of 0·01 Ω, four-way key, accumulator, a shunt box, a commutator, and jockey.

Theory. Referring to the figure given below, if points a, b, c and d are found on the meter bridge wire such that these points are at the same potentials as the terminals A, B, C, D respectively of the unknown low resistance and the standard low resistance, and if I_1 and I_2 are currents through the two branches of the circuit, then



(Fig. 6.30)

$$V_A - V_B = XI_1 = V_a - V_b = l_1 \rho I_1 \quad \cdots \quad (1),$$

and

$$V_C - V_D = RI_2 = V_c - V_d = l_2 \rho I_2$$

where l_1 and l_2 are the lengths of ab and cd of the bridge wire, and ρ is the resistance per unit length of the wire.

$$\therefore \quad \frac{X}{R} = \frac{l_1}{l_2}, \text{ or } X = \frac{l_1}{l_2} \times R.$$

Procedure. (i) Make circuit connections as shown in the figure given above. Take care to connect the unknown low resistance and the standard low resistance to the bridge by short thick wires.

(ii) Take a resistance of 1Ω in the shunt S and keep the resistance from the rheostat in the circuit at its maximum value. Now close the key K_1 of the four way key. Press the jockey lightly and slide it over the bridge wire to find the point 'a' for no deflection in the galvanometer. Make the arrangement sensitive by increasing the value of shunt across the galvanometer and also by decreasing the rheostat resistance, and determine accurately the point 'a'. Reverse the direction of current using the commutator and again determine the point 'a'. Take the mean of these two observations.

(iii) Now open the key K_1 and close the key K_2 and determine the position 'b' for no current in the galvanometer following the same procedure as described in (ii).

(iv) Similary, by successively closing K_3 and K_4, determine the positions 'c' and 'd' for no current in galvanometer.

(v) From the determination of positions a, b, c and d find the lengths l_1 and l_2 in cm and calculate X.

(vi) Repeat all the above observations at least thrice.

Observations

$R = 00{\cdot}1\ \Omega$

No. of observation	Points of no deflection												Length l_1 in cm	Length l_2 in cm
	a			*b*			*c*			*d*				
	Direct I	R	Mean	Direct I	Reverse I	Mean	Direct I	Reverse I	Mean	Direct I	Reverse I	Mean		
1														
2														
3														

Calculation and Result.

Mean $l_1 = \ldots\ldots$cm,

Mean $l_1 = \ldots\ldots$ .cm.

$$X=\frac{l_1}{l_2}\times 0{\cdot}01\ \Omega.$$

Note. The experiment needs a special care if the points '*a*' and '*b*' are not found on the bridge wire, but on the strips connecting the ends of the wire. In that case a meter bridge with four gaps (not two only) at its strip should be used. The resistances X and R should be placed in the 2nd and 3rd gaps, and the first and fourth gaps should be closed by wires of about 15 cm in length. This will bring the points '*a*' and '*b*' on the bridge wire.

ASSOCIATED EXPERIMENT

1. To perform an experiment to change the range of a given ammeter by *n* times.

An ammeter is used to measure the current in the path of a circuit. Hence it is connected in the path in series. It is, therefore, necessary that the resistance of the ammeter must be low in order that it may only negligibly affect the main current by its inclusion. The main experiment regarding the change of range of the ammeter should, therefore, be the measurement of the low resistance of the ammeter following the procedure described in Expt. 12.

Let $X\Omega$ be the resistance of the ammeter, and let its range be 0—m amperes. The maximum current which should be sent through this galvanometer is m amperes. Now we desire to change its range by n times, i.e., its range is to be converted to 0–nm ampere. Out of the maximum current of nm amperes, only m ampere should flow through the ammeter, and the rest should be arranged to flow through a shunt of resistance S. The value of the required shunt will be given by

$$m=\frac{S}{S+X}nm$$

or

$$nS=S+X,$$

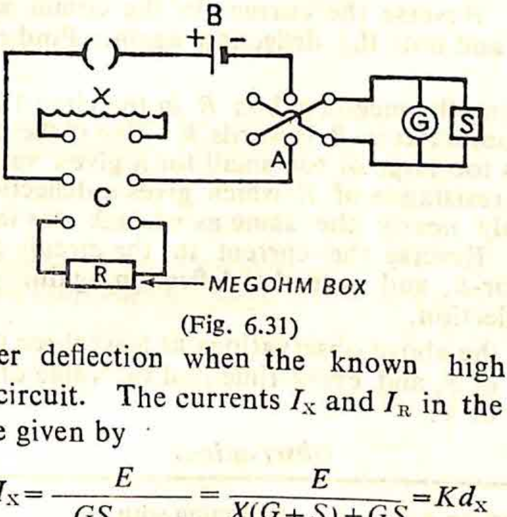
$$S=\frac{X}{n-1}.$$

If the range is to be changed by 10 times, $n=10$, and the required S will be $\frac{X}{9}$ Ω. A resistance of $\frac{X}{9}$ Ω when placed parallel to the ammeter will change to its range ten times.

EXPERIMENT 13. To measure a high resistance (or the resistance of a voltmeter.)

Apparatus. Megohm box, a suspended coil galvanometer with lamp and scale arrangement, two accumulators each of 2 volts, a resistance 0—10 Ω to be used as a shunt, a key, two Pohl commutators, and a high resistance (this may be a voltmeter).

Theory. A wheatstone bridge becomes insensitive for measurement of high resistances. Hence a different approach for measurement of high resistance is necessary. A method which may be adopted is to allow currents to flow from a battery alternately through the unknown high resistance and through a known high resistance, and to note the deflection of the galvanometer coil connected in the circuit in both the cases due to the currents flowing through it. Referring to the figure given below, let d_X be the galvanometer deflection when the unknown high resistance X is connected in the circuit, and d_R be the galvanometer deflection when the known high resistance is brought in the circuit. The currents I_X and I_R in the circuit in the two cases will be given by



(Fig. 6.31)

$$I_X=\frac{E}{\frac{GS}{G+S}+X}=\frac{E}{X(G+S)+GS}=Kd_X$$

and $$I_R=\frac{E}{\frac{GS}{G+S}+R}=\frac{E}{R(G+S)+GS}=Kd_R$$

where E = e.m.f. of the accumulator.

$$\therefore\quad \frac{I_X}{I_R}=\frac{d_X}{d_R}=\frac{R(G+S)+GS}{X(G+S)+GS}=\frac{R\left(1+\frac{G}{S}\right)+G}{X\left(1+\frac{G}{S}\right)+G}.$$

If the shunt is cut off to make S=infinite, then

$$\frac{d_X}{d_R}=\frac{R+G}{X+G}=\frac{1+\dfrac{G}{R}}{\dfrac{X}{R}+\dfrac{G}{R}}.$$

Again if R is very large compared with G, $\frac{G}{R}\to 0$, and

$$\frac{X}{R}=\frac{d_R}{d_X}, \quad \text{or} \quad X=\frac{d_R}{d_X}\times R.$$

Procedure. (i) Make circuit connections as shown in the circuit diagram. The Pohl commutator B is to be used with its cross-pieces removed. Do not take any resistance in the shunt S to start with. Bring the unknown resistance X in the circuit by throwing the rocker of the commutator B towards X, and then adjust the shunt resistance until a galvanometer deflection of about 15 cm is obtained. Note this deflection. Reverse the current in the circuit with the help of commutator A and note the deflection again. Find the mean of the two deflections.

(ii) Now bring the megohm box R in the circuit by throwing the rocker of the commutator B towards R. See if the deflection in the galvanometer is too large or too small for a given value of R. Make a choice of the resistance of R which gives a deflection between 5 to 25 cm, preferably nearly the same as when X was in circuit. Note this deflection. Reverse the current in the circuit with the help of the commutator-B, and note the deflection again. Find the mean value of the deflection.

(iii) Repeat the above observations at least three times with three different values of S, and every time find the value of X. Then find the mean value of X.

Observations

No. of observations	S in Ω	Deflection with X (cm)			Deflection with R (cm)			R in Meg. Ω	X in Meg. Ω	Mean X in Meg. Ω
		Direct C	Reverse C	Mean (d_X)	Direct C	Reverse C	Mean (d_R)			
1	500	20·0	20·5	20·25	17·5	18·0	17·75	0·8	0·7011	0·7013
2	400	17·1	16·9	17·00	15·1	14·7	14·90	0·8	0·7013	
3	300	13·7	13·9	13·80	12·2	12·0	12·10	0·8	1·7015	

Note. (i) The choice of the shunt should be so made that both d_X and d_R have large values for better accuracy of the result.

(ii) All the connecting wires should be put on porcelain insulators in order that the working table does not introduce any resistance in the circuit.

ASSOCIATED EXPERIMENTS

1. To perform a suitable experiment to change the range of a given voltmeter.

Hints. A voltmeter is used to measure the potential difference between two points in a circuit. Hence it is connected in parallel to that branch of the circuit across the two points. It is necessary that the voltmeter should draw only a negligibly small current from the circuit in order that the potential difference across two points, which is to be measured, is not appreciably altered. The resistance of the voltmeter must, therefore, be high in order that it may take negligibly small current. Hence the main experiment regarding the change of the range of the voltmeter is the measurement of the high resistance of the voltmeter following the procedure described in Expt. No. 13.

Let $X\Omega$ be the resistance of the voltmeter, and let its range be 0—m volts. The maximum potential difference which should be applied across the voltmeter is, therefore, m volts. Now we desire to change its range by n times, i.e, its range is to be converted to 0—nm volts. Out of the maximum voltage of nm volts, only m volts should be applied to the voltmeter, and the rest should be allowed to fall over a resistance of $R\ \Omega$ connected in series with the voltmeter. The value of the required series of resistance will be given by

$$m+R\frac{m}{X}=nm$$

or

$$\frac{R}{X}+1=n$$

or

$$R=(n-1)X.$$

If the range is to be changed 10 times, $n=10$, and the required R will be $9X\ \Omega$, a resistance of $9X\ \Omega$ when placed in series with the voltmeter will change to ten times.

2. To perform an experiment to convert the given voltmeter to an ammeter of the same range.

Hints. The main experiment regarding the conversion of a voltmeter into an ammeter of the same range is the measurement of the high resistance of the voltmeter.

Let the voltmeter be of the range 0—m volts, and let its resistance be $X\Omega$. It can draw a maximum current of $\frac{m}{X}$ ampere. To convert it into an ammeter of 0—m amperes range, out of the maximum of m amperes of current only $\frac{m}{X}$ amperes should pass through the instrument; the rest $m\left(1-\frac{1}{X}\right)$ amperes should be by-passed through a shunt S connected across the instrument. The value of the required shunt is given by

$$\frac{m}{X}=\frac{S}{S+X}\cdot m, \text{ or } S+X=SX$$

$$\text{or} \qquad S(X-1)=X, \qquad \therefore\ S=\frac{X}{X-1}=\frac{1}{1-\frac{1}{X}}.$$

EXPERIMENT 14. **To determine the internal resistance of a cell by potentiometer method.**

Apparatus. A stretched wire potentiometer, a Daniell cell, an accumulator, a suspended coil galvanometer with lamp and scale arrangement, a resistance box of 0—20,000 Ω, a shunt box, two keys, a resistance box of 0—100 Ω, jockey, and an ammeter of 0—0· ampere range.

Theory. When no current is drawn from a cell, the potential difference across its terminals is the e.m.f. of the cell. If a current is drawn from the cell then the potential difference measured across its terminals will be less than the e.m f. of the cell by an amount equal to the drop of potential inside the cell itself. Referring to the figure given below, if the cell C is not sending a current through the resistance r, then the potential difference across the length $AP=l_1$ of the potentiometer wire is equal to the e.m.f. 'e' of the cell. When the cell sends a current through r, then the potential difference across its terminals becomes equal to the potential difference across the length $AQ=l_2$ of the potentiometer wire.

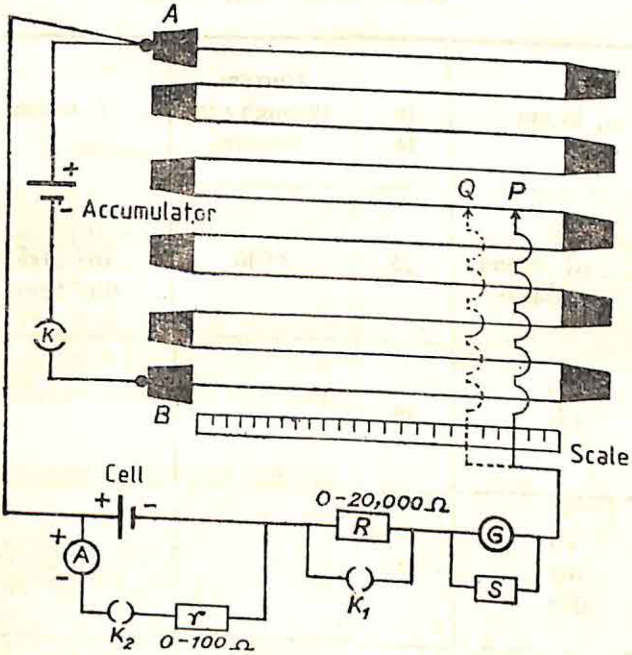
Thus, $$e = l_1 \rho \times I \qquad \ldots (1),$$

and $$\frac{er}{r+B} = l_2 \rho I \qquad \ldots (2),$$

where I = current in the wire of the potentiometer, ρ is the resistance per unit length of the potentiometer wire, and B = internal resistance of the cell.

$$\therefore \qquad \frac{l_1 \rho I r}{r+B} = l_2 \rho I, \text{ or } \frac{r+B}{r} = \frac{l_1}{l_2}$$

or $$B = r\left(\frac{l_1 - l_2}{l_2}\right).$$



(Fig. 6.32)

Procedure. (i) Make circuit connections as shown in the figure given above. Have a resistance of 15,000 Ω is the resistance box R, and of 1 Ω in S. Keep the key K_1 and K_2 open. Close the key K. Now, press the jockey lightly and move it along the wire to find a point P on the wire at which the galvanometer deflection is zero. Increase the shunt S, and try to find the point P more accurately. Finally close K_1 to make the arrangement quite sensitive, and find the position P. Note the length l_1 cm of wires from A to P. Take three observations for l_1.

(ii) Now, open K_1 and K. Take out a resistance of 25 Ω from the box r. Keep R = 15,000 Ω. Close the keys K and K_2, press the jockey lightly and move it along the wire to find the point Q on the wire at which the galvanometer deflection is zero. Gradually make the arrangement sensitive by increasing S and finally closing K_1, and find accurately the position Q. Note this position, i.e., the length l_2 cm of the wires from A to Q. Take three observations for l_2.

(iii) Repeat the determination of the point Q at $r = 25\ \Omega$, $30\ \Omega$, $35\ \Omega$, $40\ \Omega$ and $45\ \Omega$, every time noting the current through it by the ammeter A.

(iv) Calculate the internal resistance of the cell corresponding to the five values of current drawn from it.

Observations and Results

No. of observations	l_1 in cm	r in Ω	Current through r in Amperes	l_2 in cm	B in Ω
1	...... (i) ...... (ii) Mean ......(iii) 463·8	25	0·040	... .. (i) ...... (ii) Mean ......(iii) 529·6	3·55
2	(i) (ii) (iii)	30			
3	(i) (ii) (iii)	35			
4	(i) (ii) (iii)	40			
5	(i) (ii) (iii)	45			

Graph. Plot a graph with current drawn from the cell on x-axis, and the internal resistance of the cell on the y-axis, and draw your conclusion from the graph.

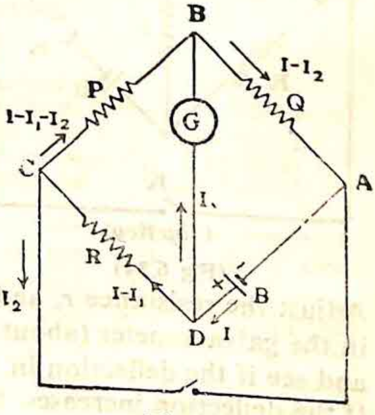
Note. (i) A change in internal resistance of the cell with the change of current drawn from it will be observed. This is due to the polarisation of the cell which increases as the current drawn from it increases. The polarisation effect is low when the current drawn from the cell is small, but in that case p.d. across r will be small and this will make $l_2 - l_1$ small. Consequently, the accuracy in the determination of B will suffer. Hence a compromise between the current drawn and the value of $l_2 - l_1$ is needed. The compromised value of r can be known only from the graph drawn with B against the current drawn from the cell.

(ii) Current should be drawn from the cell only for a short time in order that the cell may recover quickly. Therefore, K_2 should be closed only for a short time.

EXPERIMENT 15. To determine the Internal Resistance of a cell by Mance's method.

Apparatus. A P.O. box, the Daniell cell, suspended coil galvanometer with lamp and scale arrangement, two resistance boxes, a plug key, and a tap key.

Theory. The figure given below is the diagram of a Wheatstone bridge in which the fourth arm contains the cell, and the usual position of the battery or cell is taken by a tap key.



(Fig. 6.33)

Applying Kirchhoff's law to the mesh ADB,

$$BI + GI_1 + Q(I - I_2) = E \quad .. \ (1),$$

and applying the same law to the mesh DCB,

$$R(I - I_1) + P(I - I_1 - I_2) - GI_1 = 0 \ .. \ (2)$$

where E is the e.m.f. of the cell, B is the resistance of the cell, and G is the resistance of the galvanometer.

From equation (1),

$$I = \frac{E - I_1 G + Q I_2}{B + Q}.$$

After putting this value of I in equation (2), we get

$$\frac{RE - RI_1G + QI_2R}{B+Q} - RI_1 + \frac{PE - I_1GP + QI_2P}{B+Q} - PI_1 - PI_2 - GI_1 = 0$$

$$\text{or} \quad I_1[RG+(B+Q)\,R+GP+(P+G)\,(B+Q)]$$
$$=(P+R)\,E+I_2\,[RQ+QP-P\,(B+Q)].$$

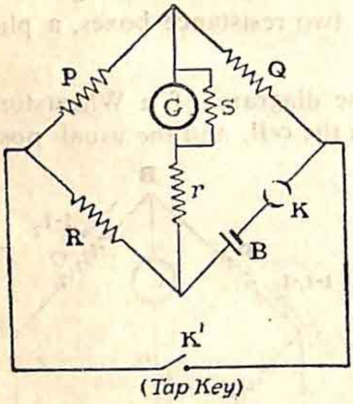
I_1 will be independent of I_2, if

$$Q\,(R+P)=P(B+Q)$$
$$\text{or} \quad QR=PB$$
$$\text{or} \quad \frac{P}{Q}=\frac{R}{B}.$$

This means that if P, Q and R are so adjusted that the relation $\frac{P}{Q}=\frac{R}{B}$ is satisfied, then whether the tap key is closed or not, the current through the galvanometer remains unchanged. After establishing this condition, B may be calculated from the relation,

$$B=R.\frac{Q}{P}.$$

Procedure. (i) Make circuit connections as shown in the diagram given below. Take P, Q and R resistances from the P. O. Box, and connect B in the fourth arm of the bridge with thick short wires. Connect one terminal of a shunted galvanometer at the junction of P and Q, and the other terminal at the junction of R and the battery with a series resistance r of about 5000Ω.



(Fig 6.34)

(ii) Keep all the keys of the shunt closed. Take 100 Ω in both P and Q arms and 10 Ω in R arm. Keeping the tap key opened, close the key K. Adjust the resistance r, and the shunt S to get a full scale deflection in the galvanometer (about 40 to 50 cm). Now close the tap key K' and see if the deflection in the galvanometer increases or decreases. If the deflection increases, then R is more than the value required for condition $\frac{P}{Q}=\frac{R}{B}$, but if it decreases, then R is less than the value required for the balance. Adjust the value of R gradually until out of two values of R differing by one ohm if for one resistance the deflection in the galvanometer increases, then for the other value the deflection decreases when the tap key is closed. Let these two values of R be n and $n+1$ ohms.

(iii) Now make $P = 1000\ \Omega$, and $Q = 100\ \Omega$, and adjust R between $10n$, and $10(n+1)$ ohm until for two values of R differing by one ohm, the changes in galvanometer deflection are in opposite senses when the tap key is closed. Let these values of R be m and $m+1$ ohm.

(iv) Make $P = 1000\ \Omega$, and $Q = 10\ \Omega$ and adjust R between $10m$ and $10\ (m+1)$ ohm until a value of R is reached at which closing the tap key does not produce any change in the deflection of the galvanometer. Calculate B from this value of R, and the values of P and Q as mentioned above.

Observations

P in Ω	θ in Ω	$\frac{Q}{P}$	R in Ω	Whether deflection increased or decreased	Conclusion about B
100	100	1	10	decreased	$B < 10\ \Omega$
			5	decreased	$B < 5\ \Omega$
			2	decreased	$B < 2\ \Omega$
			1	decreased	$B > 1\ \Omega$
1000	100	1/10	20	decreased	$B < 2{\cdot}0\ \Omega$
			10	increased	$B > 1{\cdot}0\ \Omega$
			18	decreased	$B < 1{\cdot}8\ \Omega$
			17	increased	$B > 1{\cdot}7\ \Omega$
1000	10	1/100	180	decreased	$B < 1{\cdot}80\ \Omega$
			170	increased	$B > 1{\cdot}70\ \Omega$
			175	increased	$B > 1{\cdot}75\ \Omega$
			176	No change	$B = 1{\cdot}76\ \Omega$
			177	decreased	$B < 1{\cdot}77\ \Omega$

Note. (i) If no change in deflection is noticed not for only one value of R, but for several values of the resistance, then the mean of all the values should be taken to be the value of R for calculation of B.

(ii) A higher value of P and Q in the experiment is desirable in order that only a small current is drawn from the cell and hence the polarisation effect is small. It is also desirable to adjust the value of R starting from a high value for the same reason as mentioned above.

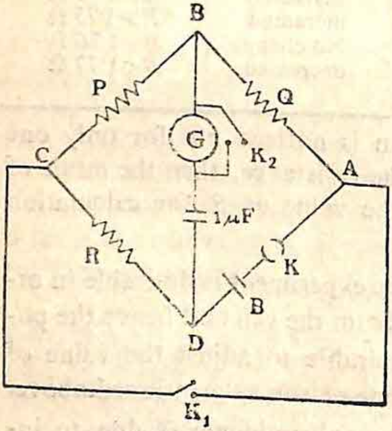
(iii) A decrease in deflection in the galvanometer is due to increase in the value of R and also due to polarisation of the cell as the current flows through it. But while the decrease in deflection is gradual due to polarisation, the decrease in deflection, due to a higher value of R than is desired, takes place with a jerk. Hence it is quite likely that a gradual decrease in deflection may be noticed even if the condition $P/Q=R/B$ has been established. Hence, all that is necessary is to observe if the change of deflection is jerky, and ignore any gradual change of deflection that might occur.

(iv) The key K should be closed only for a short time to enable the cell to recover soon.

EXPERIMENT 16. To measure the internal resistance of a cell by Lodge's modified method.

Apparatus. Daniell cell, a high resistance suspended coil ballistic galvanometer with lamp and scale arrangement, a 1 μF condenser, a plug key, two tap keys and a P.O. box.

Theory. In Lodge's modification of Mance's method the resistance R in series with the galvanometer is replaced by a condenser and the shunt S across the galvanometer is replaced by a tap key across it. The condenser is charged by closing the tap key across the galvanometer. The potential difference between the points B and D will change when the K_1 is closed keeping K_2 opened. The charge over the condenser will thus change. This will result into a sudden flow of current through the galvanometer due to which a throw of the galvanometer coil will be observed. If the resistances P, Q, R have been adjusted to satisfy the relation $P/Q=R/B$, then there will be no change of potential difference between the points B and D, so that when the tap key K_1 is closed, no throw of the galvanometer coil will be observed.



(Fig. 6.35)

Procedure. (i) Make circuit connections as shown in the figure. Take 100 Ω in both P and Q arms, and 10 Ω in R arm. Press the tap key K_2 and then close the key K to charge the condenser. (Closing K_2 during charging saves the galvanometer from the damaging effect of the charging current). Now open K_2. The galvanometer coil will remain undeflected. Close the tap key K_1 and note the sense of the galvanometer throw.

(ii) Now make R high and note the sense of galvanometer throw when the key K_1 is closed after charging the condenser again by the process described above. Again make R quite low, and note the sense of the galvanometer throw when the key K_1 is closed after charging the condenser. Gradually adjust R until two values of R differing by 1 Ω, say n and $n+1$ Ω, are obtained for which the galvanometer throws are of opposite senses, when K_1 is closed.

(iii) Now make $P=1000$ Ω, and $Q=100$ Ω, and adjust R between $10n$ and $10(n+1)$ ohm until for two values of R differing by one ohm, the galvanometer throws are observed in opposite senses when the key K_1 is closed. Let these values of R be m and $m+1$ ohm.

(iv) Make $P=1000$ Ω, and $Q=10$ Ω and adjust R between $10m$ and $10(m+1)$ ohm until a value of R is reached at which closing of the tap key K_1 does not produce any throw in galvanometer. Calculate B from this value of R, and the values of P and Q as mentioned above.

Observations

Make the same table a s in Expt. No. 15 having a column for sense of galvanometer throw after the column for R.

Note. (i) During the experiment the tap key K_2 should be used to damp down the oscillations of the galvanometer coil.

(ii) The current from the cell should be drawn only for a short time to enable the cell to recover quickly ftom the effect of polarisation.

(iii) The choice of high resistances for P, Q will reduce the polarisation effect.

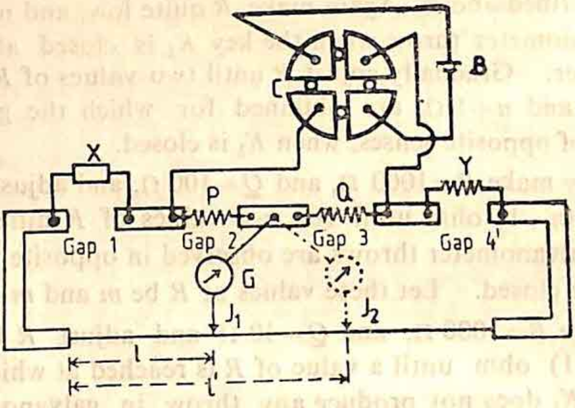
(iv) The advantage of Lodge's modification is that by using a very sensitive galvanometer, even a very small potential difference between B and D can be detected.

(v) The method has also the advantage that here one has to observe the throw and not a change in deflection which becomes inconvenient, when the charge tends to be very small.

EXPERIMENT 17. **To construct an one ohm coil using a Carey Foster's bridge.**

Apparatus. A meter bridge with four gaps to be used as Carey Foster's bridge, standard one ohm coil, P. O. Box, commutator, jockey, two V-shaped copper plates, german silver wire.

Description of special apparatus. CAREY FOSTER'S BRIDGE :



(Fig. 6.36)

The circuit diagram of a Carey Foster bridge has been shown above. It uses a meterbridge of four gaps. The middle gaps (2, 3) have equal resistances P and Q. The left gap (1) has a resistance box X and another resistance Y is placed in the right gap (4). Let the null point be obtained at J_1, at a distance of l cm from the left end of the bridge wire in this situation. On interchanging the resistances X and Y, let the null point be obtained at J_2, at a distance of l' cm from the same left hand end of the bridge wire. If ρ be the resistance of the bridge wire per cm, then the difference between X and Y is given by $X-Y=\rho(l'-l)$.

To determine ρ, Y is made zero so that

$$\rho=\frac{X}{l'-l}.$$

A Carey Foster bridge is quite useful in finding out the difference between two resistances of nearly equal value.

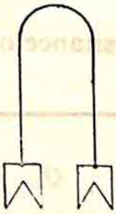
Theory. Let L cm be the length of a sample of german silver wire whose resistance as measured with a P.O. Box is $R'\ \Omega$. Hence a sample of length $\frac{L}{R'}$ cm will have a resistance of 1 Ω. In practice it may not be exactly one ohm. Hence to make an exactly 1 Ω coil, a sample of length somewhat smaller than L/R' may be taken and it may be rubbed by sand paper to gradually increase its resistance to 1 Ω.

The sample will form the resistance Y of the Carey Foster bridge and the resistance X will be a standard one ohm coil so that when Y becomes equal to X, $l'-l$ becomes zero, i.e. l becomes equal to l'.

The measurment of ρ is required to find the difference between the resistance of the coil prepared and the standard one ohm resistance. For this purpose the resistances P and Q are each made equal to one ohm. A thick copper strip of zero resistance is connected for Y. Then resistance in the box X is adjusted so that the null point J_1 is at a distance of nearly 5 cm (or even less) from the left end of the bridge wire. This is noted to give l. The copper strip and the resistance box are then interchanged and the null point J_2 is obtained. This is noted to give l'. From the l and l' thus obtained, ρ is calculated putting $Y=0$, and $X=$the resistance taken in the resistance box X.

Procedure 1. A sample of german sliver wire of about one metre was taken and its length was measured. Its resistance was measured with P.O. box following the usual procedure of resistance measurement by P.O. box.

2. The length L cm out of this wire required to have a resistance of 1 ohm is then calculated. A length about 10% less than this length is then cut and its ends are soldered to two V-shaped copper plates (Fig. 6.37).



(Fig. 6.37)

3. A Carey Foster's bridge as shown in the figure above is set up. Two thick copper strips are connected to the 1st gap and the 4th gap so as to make $X=Y=0$, and a one ohm coil is put in each of 2nd and the 3rd gap making $P=Q=1\ \Omega$. Null point on the bridge wire is then determined by shiting the jockey over it, for both direct and reverse currents, making use of the commutator. This determines the null point for the equality of X and Y. Let it be at a distance l_0 cm from the left end of the bridge wire.

4. The two copper strips are now removed. The gap 4 is now filled by connecting the sample wire (the coil) whose resistance is about 10% less than 1 Ω, and the gap 1 is filled by a standard one ohm coil. The jockey is then moved over the bridge wire to find the null point J_1 at a distance of l cm from the left end of the bridge wire. This is obtained for both the direct and the reverse currents, making use of the commutator. The average of the two as the value of l is used in calculation. As the resistance of the sample wire (the coil) is less than 1 Ω, l will not be equal to l_0.

5. The wire is gently rubbed by a sand paper to increase its

resistance and after every rubbing the new null point J_1 and hence the new value of l is determined until l becomes equal to l_0 when the coil closely attains a resistance of one ohm.

6. Now interchange the positions of this coil and the standard one ohm resistance in the bridge. Find the null point J_2 and note the distance l' of the null point from the left hand end of the bridge wire. This is obtained both for direct and reverse currents, making use of the commutator Use the average of the two as the value of l'.

7. Determine ρ by the procedure outlined in the theory portion of this experiment. Calculate the resistance of the coil (Y) by

$$Y = X + \rho(l' - l) = 1 + \rho(l' - l).$$

If the value of Y does not exceed 1 Ω by more than 1%, the coil is well prepared. But if it exceeds 1 Ω by more than this, its needs further rubbing to bring its resistance very close to 1 Ω.

Observations

(i) Resitance of the sample of length L $= 94{\cdot}0$ cm by P.O. Box.

P	Q	P/Q	R	Sense of the deflection of G	Conclusion
10 Ω	10 Ω	1	∞	Right	$R' < \infty$
			0	Left	$R' > 0$
			10	Right	$R' < 10$ Ω
			5	Right	$R' > 5$ Ω
			3	Right	$R' < 3$ Ω
			2	Left	$R' > 2$ Ω
10 Ω	100 Ω	1/10	30	Right	$R' < 3{\cdot}0$ Ω
			20	Left	$R' > 2{\cdot}0$ Ω
			28	Right	$R' < 2{\cdot}8$ Ω
			27	Left	$R' < 2{\cdot}7$ Ω
10 Ω	1000 Ω	1/100	280	Right	$R' < 2{\cdot}80$ Ω
			270	Left	$R' > 2{\cdot}70$ Ω
			275	Right	$R' < 2{\cdot}75$ Ω
			274	Right	$R' < 2{\cdot}74$ Ω
			273	Null	$R' = 2{\cdot}73$ Ω
			272	Left	$R' > 2{\cdot}72$ Ω

Length of wire required for preparing 1 Ω coil

$$= \frac{94{\cdot}0}{2{\cdot}73} = 34{\cdot}43 \text{ cm.}$$

90% of this length $= 30{\cdot}99$ cm.

(i) Determination of l_0 :

$$X=0,\ Y=0,\ P=1\ \Omega,\ Q=1\ \Omega.$$

No. of Obs.	Null point with direct current (cm)	Null point with reversed current (cm)	Mean null point (l_0)
1 2 3 4	$\left.\begin{matrix}50{\cdot}3\\50{\cdot}2\\50{\cdot}1\\50{\cdot}1\end{matrix}\right\}50{\cdot}20$	$\left.\begin{matrix}50{\cdot}0\\50{\cdot}0\\50{\cdot}1\\50{\cdot}1\end{matrix}\right\}50{\cdot}05$	50·12 cm

(ii) Determination of l for Y close to 1 Ω :

$$P=1\ \Omega,\ Q=1\ \Omega,\ X=1\ \Omega.$$

Null point on gradual rubbing of the wire (cm)			Conclusion
Direct current	Reversed current	Mean (cm)	
40·90	40·70	40·80	$Y>1\ \Omega$
48·60	48·60	48·60	$Y>1\ \Omega$
49·20	49·10	49·15	$Y>1\ \Omega$
49·85	49·83	49·84	$Y>1\ \Omega$
49·90	49·85	49·88	$Y>1\ \Omega$
$50{\cdot}12\left\{\begin{matrix}50{\cdot}10\\50{\cdot}15\\50{\cdot}10\end{matrix}\right\}$	$50{\cdot}13\left\{\begin{matrix}50{\cdot}15\\50{\cdot}10\\50{\cdot}15\end{matrix}\right\}$	50·13	$Y>1\ \Omega$

$$\therefore\quad l=50{\cdot}13\text{ cm.}$$

(iii) Determination of l' :

No. of obs.	Null point with direct current (cm)	Null point with reversed current (cm)	Mean null point (l')
1 2 3	$\left.\begin{matrix}50{\cdot}40\\50{\cdot}45\\50{\cdot}50\end{matrix}\right\}50{\cdot}45$	$\left.\begin{matrix}50{\cdot}45\\50{\cdot}50\\50{\cdot}50\end{matrix}\right\}50{\cdot}$	50·47 cm

(iv) Determination of ρ :

$$P = 1\ \Omega,\ Q = 1\ \Omega,\ Y = 0\ \Omega.$$

No. of obs.	X in Ω	l_1 in cm			l_2 in cm		
		Direct current	Reversed current	Mean	Direct current	Reversed current	Mean
1	2 Ω	4·20	4·30	4·25	96·10	96·00	96·15
2		4·30	4·40	4·35	95·90	96·10	96·00
		4·10	4·20	4·15	96·00	96·10	96 05

Mean $l_1 = 4{\cdot}25$ cm.

,, $l_2 = 96{\cdot}07$ cm.

$$\therefore \quad \rho = \frac{X}{l_2 - l_1} = \frac{2}{96{\cdot}07 - 4{\cdot}25} = \frac{2}{91{\cdot}72}$$

$$= 0{\cdot}022 \text{ ohm/cm.}$$

Hence $Y = 1 + 0{\cdot}022\ (50{\cdot}47 - 50{\cdot}13)$

$= 1 + 0{\cdot}007$

$= 1{\cdot}007\ \Omega.$

% departure from 1 Ω = 0·7%.

EXPERIMENT 18. **To determine the conductivity of an Electrolyte.**

Apparatus. Meter bridge, electrolytic cell, headphone, jockey. buzzer or low frequency oscillator, rheostat, resitance box.

Description of special apparatus. ELECTROLYTIC CELL : It is an U-shaped glass tube in which the electrolyte is filled. It carries two copper electrodes E_1 and E_2. The diameters of E_1 and E_2 are equal and slightly less than that of the tube. They can be shifted in position inside the tube and their position can be marked by thread or rubber rings on the outside of the limbs of the U-tube. The top end of the electrodes carry binding screws with which they are connected in circuit.

Theory. A sample of electrolyte of length L metre and cross-section A square metre has a resistance R ohm, so that

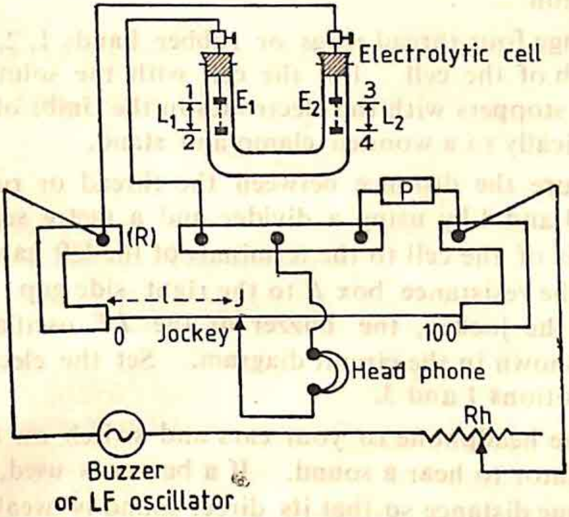
$$\frac{1}{R} = K\frac{A}{L} \text{ Mho,}$$

where K is the 'conductivity' of the electrolyte. Hence

$$K = \frac{L}{AR} \text{ Mho m}^{-1}.$$

(i) Determination of R :

R is determined by the method of determining resistance with a meterbridge.



(Fig. 6.38)

If the minimum sound is obtained when the jockey is at a distance of l cm from the left end of the bridge wire, then

$$\frac{R}{P}=\frac{l}{100-l}, \text{ or } R=\frac{lP}{100-l}\ \Omega.$$

If the resistance of the electrolyte for the points 1 and 3 of the electrodes E_1 and E_2, respectively, be R_1 Ω, and if the resistance of the electrolyte for the positions 2 and 4 of the electrodes E_1 and E_2, respectively be R_2 Ω, then

$$L=L_1+L_2, \text{ and } R=R_1-R_2.$$

'A' will be taken to be the mean cross-section of the electrodes and nearly equal to the internal cross-section of the tube.

Procedure. 1. Weigh about 5 gm of copper sulphate ($CuSO_4$, $5H_2O$) and on a filter paper by first of all counterpoising the filter paper then the salt on filter paper. Let the weight of the copper sulphate be W gm. Transfer this to a cleaned and dry measuring jar and add distilled water to it gradually to dissolve the copper sulphate. Add more distilled water to make the solution 100 c.c. in volume. The strength of this solution is $\frac{W}{100}$ gm/c.c.

2. Clean the electrolytic cell with dilute nitric acid and then remove the acid by cleaning the cell several times with tap water. Then wash it with distilled water and in the end by a small amount of the solution.

3. Arrange four thread rings or rubber bands 1, 2, 3 and 4, two on each limb of the cell. Fill the cell with the solution prepared. Push in the stoppers with the electrodes in the limbs of the cell. Fix the cell vertically to a wooden clamp and stand.

4. Measure the distance between the thread or rubber rings 1 and 2, and 3 and 4 by using a divider and a metre scale. Connect the terminals of the cell to the terminals of the left gap of the meter bridge and the resistance box R to the right side gap. Connect the headphone, the jockey, the buzzer or the *LF* oscillator, and the rheostat as shown in the circuit diagram. Set the electrodes E_1 and E_2 at the positions 1 and 3.

5. Put the headphone to your ears and switch on the buzzer or the *LF* oscillator to hear a sound. If a buzzer is used, it should be placed at some distance so that its direct sound is weak. Press the jockey on the bridge wire at the 50 cm mark and adjust the resistance in resistance box P to make the sound minimum.

6. Move the jockey over the bridge wire to find the range of the length in which the sound is minimum. Take the mean position over this range as the value of l and calculate R_1 by $R_1 = \frac{Pl}{100-l}\,\Omega$.

7. Interchange the cell and the resistance box P in their gaps. Move the jockey over the bridge wire to find the range of minimum sound. Take this mean position over this range as the value of l and again calculate R_1 by $R_1 = \frac{P(100-l)}{l}\,\Omega$.

8. Take the mean of the two R_1 values.

9. Set the electrodes E_1 and E_2 at the positions 2 and 4 and determine R_2 by the same process as used for R_1.

10. Calculate $R = R_1 - R_2$ and $L = L_1 + L_2$.

11. Repeat the experiment for at least five different concentrations of the electrolyte.

12. To determine A, clean the electrolytic cell with tap water, and take water in it between the marks 1 and 3. Transfer this water in a measuring cylinder and find its volume V_1. Then take water in the cell between the marks 2 and 4 and similarly find its volume V_2. The volume in lengths L of the cell $= V_1 - V_2$ from which obtain

$$A = \frac{V_1 - V_2}{L}.$$

In case the two quantities of water are not sufficient, determine V_1 and V_2 by weighing the two quantities of water.

Observations

$L_2 = \ldots\ldots, L_2 = \ldots\ldots, L = L_1 + L_2 = \ldots\ldots$

Observations for 1st concentration :

Weight of filter paper = ...

Weight of filter paper + copper sulphate = ...

Weight of copper sulphate = ... = W gm.

Concentration of the solution $= C = \dfrac{W}{100}$ gm/cc.

Measurement of R_1 and R_2—

Measurement of R_1 or R_2	Position of the cell	P in ohm	Range for l	Mean l	$100-l$	Value of R_1 or R_2
R_1	In left side gap		(i) 48·1 to 52·2 (ii) ...... (iii)			$R_1 =$
R_1	In right side gap		(i) ...... (ii) ...... (iii)			$R_1 =$
R_2	In left side gap		(i) (ii) (iii)			$R_2 =$
R_2	In right side gap		(i) (ii) (iii)			$R_2 =$

Mean $R_1 = \ldots.$ohm

„ $R_2 = \ldots.$ohm

$R = R_1 - R_2 = \ldots.$

(Similarly take observations of R_1 and R_2 for other concentrations of the electrolyte.)

Volume of water between mark 1 and 3 = ... = V_1

„ „ „ 2 and 4 = ... = V_2.

$$\therefore \quad A = \frac{V_1 - V_2}{L} = \ldots.$$

Result.

$$K=\frac{L}{AR}=\frac{\cdots\cdots}{\cdots\cdots}=\ldots\text{Mho m}^{-1}$$

and at the concentration $C=\ldots\ldots$ gm/cc

$=\ldots\ldots \text{kg/m}^3$.

Determine similarly K for other concentrations.

Plot a graph with K against C.

K will be found to increase with C.

Note. (i) A d.c. source is not used in this experiment as it will electrolyte the solution.

(ii) Instead of a U-tube cell, a straight cell may also be used.

EXPERIMENT 19. To determine the Mechanical Equivalent of Heat (J) by Electrical method.

Apparatus. Joule's calorimeter, an ammeter of 0 – 5 ampere range, a voltmeter of 0 – 6 volt range, a stop-watch, a sensitive thermometer of 0 – 50°C range, a weight box, a rheostat and a storage battery of 6 volts.

Description. JOULE'S CALORIMETER : It is a nickel plated copper vessel having an ebonite lid to which are attached two binding screws connected to two thick copper leads. The copper leads are connected to a resistance wire of manganin. There are holes in the lid of the calorimeter to insert a stirrer and a thermometer. The calorimeter is usually suspended inside another copper vessel and the whole arrangement placed inside a wooden box.

Theory. The amount of work done when a current of I amperes is passed through a wire of resistance R ohm for t seconds is given by,

$$W=I^2Rt \text{ Joule}$$
$$=EIt \text{ Joule}$$

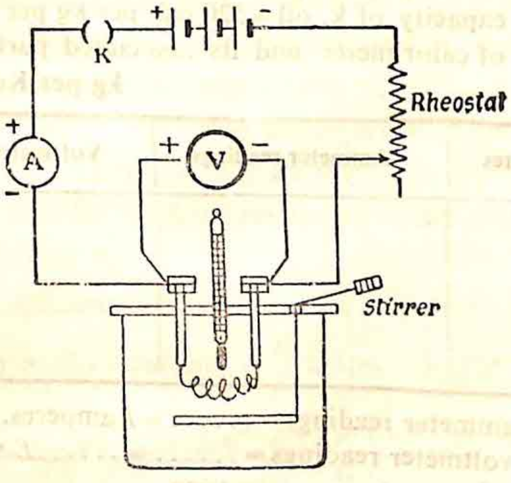
where E is the potential difference maintained at its ends, measured in volts.

This amount of work appears in the form of heat. If the heat generated is used to raise the temperature of m kg liquid of specific heat capacity S calorie per kg per Kelvin from θ_1°C to θ_2°C when placed in calorimeter of water equivalent W kg then, $\theta_2-\theta_1=$rise in temperature in Kelvin and $W=EIt=J\times(ms+w)(\theta_2-\theta_1)$.

$$\therefore\ J=\frac{EIt}{(ms+w)(\theta_2-\theta_1)} \text{ Joule/calorie.}$$

Procedure. (i) Weigh the empty calorimeter, the stirrer, and the copper frame carrying the resistance wire. Then fill up the calorimeter up to about $\frac{2}{3}$ with kerosene oil, and weigh it again together with the stirrer and the copper frame carrying the resistance wire.

(ii) Now make circuit connection as shown in the diagram given below.



(Fig. 6.39)

(iii) Close the key *K* and adjust the rheostat to read a current of 3 amperes in the ammeter. Open the key *K* and let the calorimeter cool for about 15 minutes before restarting the experiment. After 15 minutes if the thermometer reading does not change, note the temperature of the liquid and its container by reading the thermometer at least three times at intervals of one minute. Now close the key *K* and start the stop-watch simultaneously. Keep on stirring the liquid with the stirrer and go on reading the ammeter and voltmeter at intervals of 2 minutes.

(iv) When the temperature has increased by 5°C above the initial temperature, open the key and stop the stop-watch simultaneously. Note the time *t* secs. during which the current has flown from the stop-watch.

(v) Go on stirring the liquid and noting the temperature of the liquid at intervals of $\frac{1}{2}$ minute till the temperature has fallen about 3 degrees below the maximum temperature recorded. Apply radiation correction to find the actual final temperature of the liquid and its container together with its associated parts. (For the procedure of radiation correction see the Section on Heat.)

Observations

Weight of the calorimeter, stirrer and the copper frame carrying e resistance wire = ... = W_1 kg.

Weight of k. oil, calorimeter, stirrer and the copper frame carry- g the resistance wire = ... = W_2 kg.

Weight of k. oil = $W_2 - W_1$ kg = ...kg.

Specific heat capacity of k. oil = 520 cal. per kg per Kelvin.

Specific heat of calorimeter and its associated parts = 94 cal. per kg per Kelvin (copper).

Interval in minutes	Ammeter readings	Voltmeter readings
0−2		
2−4		
4−6		
6−8		
...		
...		

Mean of the ammeter readings = ... = I amperes.

Mean of the voltmeter readings = ... = ...E volts.

Time of flow of current = ... = t sec.

Temperature readings.

Readings of initial temperature = 28·1°C

$$\left.\begin{array}{l} 28{\cdot}0^\circ\mathrm{C} \\ 28\ 0^\circ\mathrm{C} \\ 28{\cdot}0^\circ\mathrm{C} \end{array}\right\} \text{Initial temp.}$$

Reading for radiation correction to get the final temperature – Same table as in the Heat Section.

Calculations and Result.

$$W = EIt \text{ Joule} = \ldots\ldots \text{Joule.}$$

Water equivalent of calorimeter and its

$$\text{associated parts} = 94 \times W_1$$

$$= \ldots\ldots \text{kg} = W \text{ kg.}$$

$$\theta_1 - \theta_2 = \ldots\ldots \text{Kelvin}$$

$$H = (W_2 - W_1 + W) \times 0{\cdot}51\,(\theta_2 - \theta_1)$$

$$\therefore\ J = \frac{W}{H} = \frac{\cdots\cdots}{\cdots\cdots} = \ldots\ldots\ldots \text{Joule/cal.}$$

Note. (i) As the e.m.f. of the battery and the resistance of the resistance wire of the calorimeter will change a little during the experiment, the ammeter and the voltmeter readings will also change by small amounts during the experiment. However, good accuracy in result is obtained by taking the mean values of ammeter and voltmeter readings for the purpose of calculation.

(ii) A small amount of inaccuracy will result if radiation correction is not made for the final temperature.

(iii) The accuracy of the result will improve if the ammeter, and voltmeter are calibrated before they are used.

(iv) A correction for the finite resistance of the voltmeter may be made in the following way :

If $R\,\Omega$ is the resistance of the voltmeter, then, while it gives a reading of E volts, it draws a current of $\frac{F}{R}$ amps. So the current in the resistance wire of the calorimeters $=\left(I-\frac{E}{R}\right)$ amperes. It is this value of current which should be used in calculations, and not the ammeter reading.

(v) Use of water as a liquid in the calorimeter may be avoided, if possible, on account of its high specific heat, and its capability of being electrolysed.

EXPERIMENT 20. To study the characteristics of a semi-conductor Diode (under foward and backward biases).

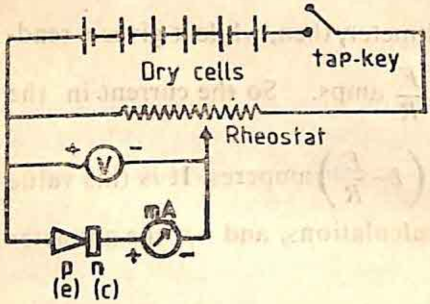
Apparatus. Six dry cells, a rheostat of about 200 Ω, a voltmeter of range 0 – 10 V, a milliammeter of 0 – 100 mA range, semi-conductor diode (*OA*75 or 05 – *SMI* or any other), a tap-key.

Description of special apparatus. SEMI-CONDUCTOR DIODE : It is usually made as a function of *n* and *p* types of germanium or silicon materials. When the *p*-material of the diode is biased positively and the *n*-material is biased negatively, a current flows through the *p-n* junction from *p* to *n* material. Such a bias across the junction is called the forward bias. If the *p*-material is biased negatively and the *n*-material is biased positively an extremely feeble current flows through the junction from *n* to *p* material. Such a bias across the junction is called the backward bias.

Theory. Under a forward bias a *p-n* junction allow a flow of current through it which increases with the magnitude of the bias. However, the increase is not linear as such the *p-n* junction offers non-ohmic resistance.

An ordinary semi-conductor diode gives a negligible current under a backward, but a special type of diode, known as the 'Zener diode' gives a very large current at a relatively large voltage which known as its break-down voltage.

Procedure. **1.** Using the dry cells arrange your circuit as shown in the figure given below. To connect the diode in the circuit under forward bias ascertain first of all as to which end of it is *p* and which end of it is the *n* side. For this purpose take a multimeter and set it in the position of ohm-measurement. Put the red terminal of the meter in contact with one terminal of the diode and touch the other terminal of the diode with the black terminal of the multimeter. If the meter shows a large deflection, then the terminal of the diode in contact with red terminal of the multimeter is the *p* terminal. But if the deflection is very small, it is the *n* terminal. Connect the diode in the circuit such that its *p* terminal is towards the positive pole of the battery.



(Fig. 6.40)

2. Press the tap key and make the voltmeter reading 1 volt and take the milliammeter reading. This is a reading under forward bias of IV.

3. Go on increasing the voltmeter reading by 1 volt by adjusting the rheostat and take the milliammeter reading everytime.

4. Now disconnect the diode and connect by reversing its terminals and take the milliammeter reading under the reversed bias condition at the reversed biases of 1 V, 2 V. . . .etc. by pressing the tap key and adjusting the rheostat.

Observations

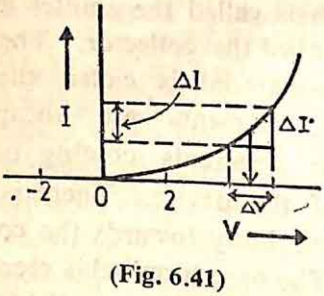
(i) Under forward bias :

No. of obs.	Forward bias volts (V)	Diode current (mA)	Forward dynamic resistance $R=\frac{\triangle V}{\triangle I}$
1	1		
2	2		
3	3		
⋮	⋮		
10	10		

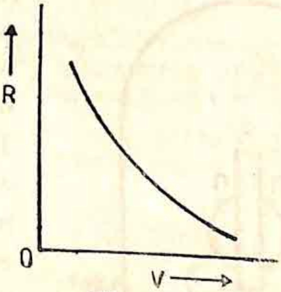
(ii) Under backward bias :

No. of obs.	Backward bias volts (V)	Diode current (mA)	Backward dynamic resistance
1	-1		
2	-2		
⋮	⋮		
5	-5		

Results. Draw a graph with forward current against the forward bias. Determine the slope of the curve at the different forward bias. This will give $\frac{\triangle I}{\triangle V}$ at different bias voltage. From this obtain the forward dynamic resistance $R=\frac{\triangle V}{\triangle I}$ at different V, and draw $R-V$ graph.



(Fig. 6.41)



(Fig. 6.42)

Draw your conclusions from the graphs and the observations.

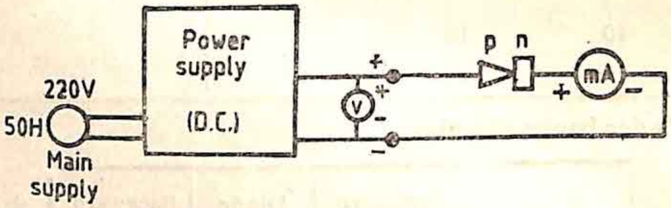
(i) As the forward bias increases, the diode current first increases slowly and then quickly.

(ii) With the increase of forward bias the forward dynamic resistance decreases.

(iii) The backward diode current is negligible at ordinary backward biases.

Precaution. Do not use a large backward bias otherwise the diode will be damaged.

Note. 1. If a stabilised power supply of low variable D.C. voltage with a built in voltmeter is available, the circuit arrangement will be more simple as shown in the figure given below :



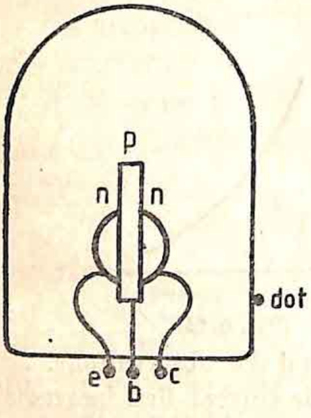
(Fig. 6.44)

2. To note the diode current at the backward biases, it is advised to use a microammeter of range 250-0-250 microamperes.

EXPERIMENT 21 A. **To draw the characteristics of a transistor in common base configuration and to obtain its current gain, α.**

Apparatus. A *p-n-p* transistor (or *n-p-n* transistor), a voltmeter of 0 – 1 V range, a voltmeter of 0 – 10 V range, two milliammeters of 0 – 1 mA range, plug keys, a variable D. C. source of 0 – 2 V, and another variable D.C. source of 0 – 6 V. (The sources may be standard power units or may be made from batteries and rheostats.)

Description. TRANSISTOR : A *p-n-p* transistor is made of *n*-type of germanium or silicon wafer sandwitched between two *p*-types of germanium wafers. One of the two *p*-materials is called the emitter and the other is called the collector. The intermediate *n*-material is called the base. The three elements are encapulated with their terminals coming out the bottom of the device. There is a dot mark on the body towards the collector terminal. The base terminal is recognised as the terminal near the collector and the third terminal is then the emitter terminal.

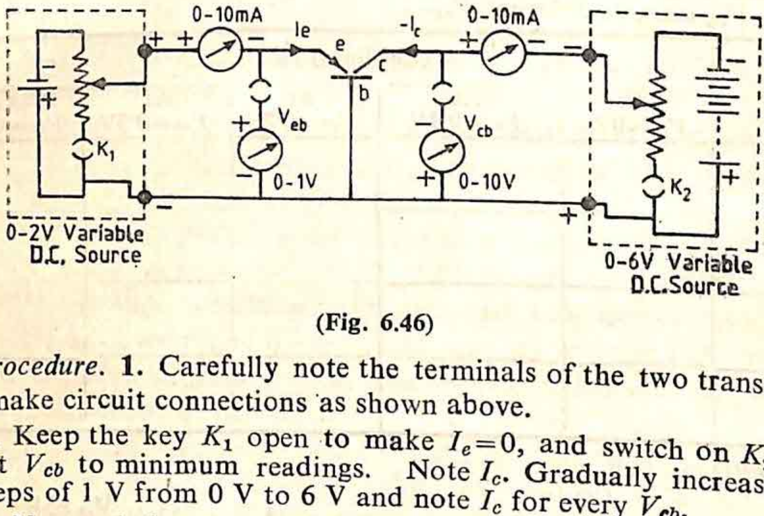


(Fig. 6.45)

Theory. The variation of collector current (I_c) which is the current between the collector and the base, with collector to base voltage (V_{cb}) at different emitter currents (I_e) (currents between the emitter and base) are shown, by a family of curves known as the output characteristics of the transistor in common base configuration in which the base is common between the input and the output circuits.

The variation of emitter current (I_e) with emitter to base voltage (V_{eb}) at different collector to base voltages (V_{cb}) are shown by a family of curves known as the input characteristics of the transistor in common base configuration.

The variation of collector current (I_c) with emitter voltage (I_e) at different collector to base voltages (v_{cb}) are shown by a family of curves known as the output-input characteristics of the transistor in common base configuration. The slope, $\triangle I_c/\triangle I_e$ of any such curve at any I_e gives the current gain, α of the transistor for the given I_e and V_{6b}.



(Fig. 6.46)

Procedure. **1.** Carefully note the terminals of the two transistors and make circuit connections as shown above.

2. Keep the key K_1 open to make $I_e=0$, and switch on K_2 and adjust V_{cb} to minimum readings. Note I_c. Gradually increase V_{cb} by steps of 1 V from 0 V to 6 V and note I_c for every V_{cb}.

3. Now switch on K_1 and adjust V_{eb} (using the rheostat) to get $I_e=0{\cdot}5$ mA. Keeping I_e at this value, by adjustment of rheostat every time, read I_c at V_{cb} from 0 V to 6 V at intervals of 1 V.

4. Repeat the above observations at $I_e=1{\cdot}0$ mA, 1·5 mA, 2·0 mA and 2·5 mA. These data will provide the output characteristics and the output-input characteristics.

5. For input chracteristics, take readings of I_e at different V_{eb} by keeping V_{cb} fixed at 0 V, 1 V, 2 V and 3 V.

6. Draw $(I_c - V_{cb})_{I_{e=const.}}$, $(I_e - I_{eb})_{V_{cb=const.}}$ and $(I_c - I_e)_{V_{cb=const.}}$ family of curves and from $(I_c - I_e)_{V_{cb}}$ curves calculate α at different I_c and V_{cb}.

Observations

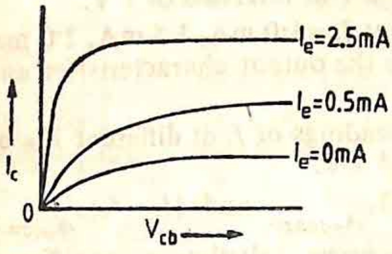
No. on the transistor : $I_c - V_{cb}$ data at different I_e—

I_e (mA)	I_c (Readings)					
	At $V_{cb}=0$	At $V_{cb}=1\text{V}$	At $V_{cb}=2\text{V}$	At $V_{cb}=3\text{V}$	At $V_{cb}=4\text{V}$	At $V_{cb}=5\text{V}$
0·0						
0·5						
1·0						
1·5						
2·0						
2·5						

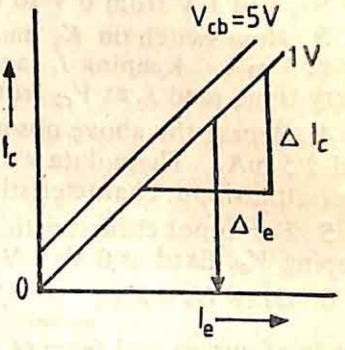
$I_e - V_{eb}$ data at different V_{cb}—

V_{cb} (V)	I_e (Readings)				
	At $V_{eb}=0\text{V}$	At $V_{eb}=0{\cdot}1\text{V}$	At $V_{eb}=0{\cdot}2\text{V}$	At $V_{eb}=0{\cdot}3\text{V}$	At $V_{eb}=0{\cdot}4\text{V}$
0·0					
—1·0					
—2·0					
—3·0					

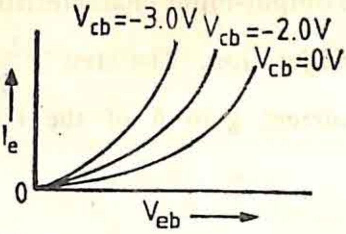
Results.



Output characteristics
(Fig. 6.47)



Output-input characteristics
(Fig. 6.48)



Input characteristics
(Fig. 6.49)

Calculation of α.

1. $\begin{cases} \text{i) At } V_{cb}=\dots, I_e=\dots, \alpha=\dots \\ \text{ii) ,, } V_{cb}=\dots, I_e=\text{ Do }, \alpha=\dots \end{cases}$

2. $\begin{cases} \text{i) At } V_{cb}=\dots, I_e=\dots, \alpha=\dots \\ \text{ii) ,, } V_{cb}=\dots, I_e=\text{ Do }, \alpha=\dots \end{cases}$

3. $\begin{cases} \text{i) At } V_{cb}=\dots, I_e=\dots, \alpha=\dots \\ \text{ii) ,, } V_{cb}=\dots, I_e=\text{ Do }, \alpha=\dots \end{cases}$

α will be found to be almost independent of V_{cb} and I_e, and it will have a value slightly less than 1.

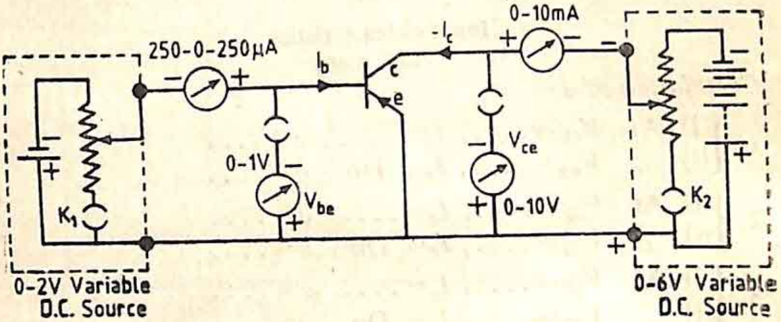
EXPERIMENT 21 B. To draw the characteristics of a transistor in common emitter configuration and to obtain its current gain, β.

Apparatus. A *p-n-p* transistor (or *n-p-n* transistor), a voltmeter of 0--1 V range, a voltmeter of 0 – 10 V range, a micro-ammeter of 0 – 200 μA range, a milliammeter of 0 – 10 mA range, plug keys, a variable D.C. source of 0 – 2 V, and another variable D.C. source of 0 – 6 V. (The sources may be standard power units or may be made from batteries and rheostats.)

Theory. The variation of the collector current (I_c) (which is the current between the collector and the emitter) with collector to emitter voltage (V_{ce}) at different basc currents (I_b) (currents between the base and the emitter) are shown by a family of curves known as the output characteristics of the transistor in common emitter configuration in which the emitter is common between the input and the output circuits.

The variation of base current (I_b) with base to emitter voltage (V_{be}) at different collector to emitter voltages (V_{ce}) are shown by a family of curves known as the input characteristics of the transistor in common emitter configuration.

The variation of collector current (I_c) with base current (I_b) at different collector to emitter voltages (V_{ce}) are shown by a family of curves known as the output-input characteristics of the transistor in common emitter configuration. The step $\frac{\triangle I_c}{\triangle I_b}$ of any such curve at any I_b gives the current gain β of the transistor for the given I_b and V_{ce}.



(Fig. 6.50)

Procedure. **1.** Carefully note the terminals of the transistor and make the circuit connections as shown above.

2. Keep the key K_1 open to make $I_b = 0$. Switch on K_2 and adjust V_{ce} to minimum reading. Note I_c. Gradually increase V_{ce} by steps of 1 V from 0 V to 6 V and note I_c for every V_{ce}.

3. Now switch on K_1 and adjust V_{be} using the rheostat to get $I_b = 50\ \mu A$. Keeping I_b at this value, by adjustment of the rheostat every time, read I_c at V_{ce} from 0 V to 6 V at intervals of 1 V.

4. Repeat the above observations at $I_b = 100\ \mu A$, $150\ \mu A$, and $200\ \mu A$. These data will provide the output characteristics and the output-input characteristics.

5. For input characteristics take readings of I_b at different V_{be} keeping V_{ce} fixed at 0 V, 1 V, 2 V and 3 V.

6. Draw $(I_c - V_{ce})_{I_b = const.}$, $(I_b - V_{be})_{V_{ce} = const.}$ and $(I_c - I_e)_{V_{ce} = const.}$ family of curves, and form $(I_c - I_b)_{V_{ce}}$ curves. Calculate β at different I_b and V_{ce}.

Observations

No. on the transistor—

$I_c - V_{ce}$ data at different I_b—

I_b (μA)	I_c (Readings)					
	At $V_{ce}=0$ V	At $V_{ce}=1$ V	At $V_{ce}=2$ V	At $V_{ce}=3$ V	At $V_{ce}=4$ V	At $V_{ce}=5$ V
0·0						
50						
100						
150						
200						

$I_b - V_{be}$ data at different V_{ce}—

V_{ce}	I_b (Readings)					
	At $V_{be}=0$ V	At $V_{be}=0{\cdot}1$ V	At $V_{be}=0{\cdot}2$ V	At $V_{ce}=0{\cdot}3$ V	At $V_{be}=0{\cdot}4$ V	At $V_{be}=0{\cdot}5$ V
0·0						
1·0						
2·0						
3·0						
4·0						
5·0						

increase of anode voltage. Under this condition the current is said to be 'space charge-limited'. Afterwards, the anode current increases only by a very small amount even though the anode voltage is greatly increased. In this condition the valve is said to be operating under 'temperature limited condition'.

The characteristic curve of a diode has a straight portion shown by AB in the figure given above. The a.c. resistance of the diode is defined as the reciprocal of the slope of the characteristic curve, i.e.,

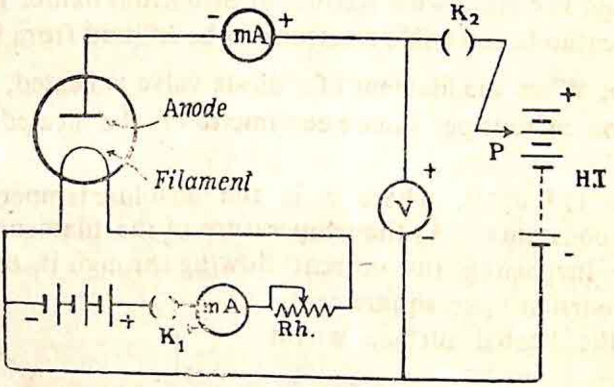
$$R_a = \text{A.C. resistance of the diode}$$

$$= \frac{\Delta V_a}{\Delta I_a}$$

$$= \frac{(V_a) \text{ at } A - (V_a) \text{ at } B}{(I_a) \text{ at } A - (I_a) \text{ at } B} \Omega.$$

The value of R_a is obviously constant in the straight portion of the characteristic curve.

Procedure. (i) Make the circuit conections as shown in the Fig. 6.57 after identifying the pins of the diode for a directly heated diode valve; otherwise for an indirectly heated diode valve make circuit connections as shown in Fig. 6.58.



(Fig. 6.57)

(ii) Starting with the maximum resistance from the rheostat in tge filament circuit, plug in the key K_1 and then adjust the filament current to half its permissible value for the given value.

(iii) Now connect the H.T. and adjust in to give about 10 volts to the plate (anode). Plug in the key K_2, and take the reading of anode current and anode voltage from the milliammeter and the voltmeter respectively.

(iv) Now go on gradually increasing the H.T. by 10 V and note every time the value of the anode current and the anode voltage.

(v) Repeat the above readings for three-fourths and full value of the permissible filament currents,

(vi) Record your data in the tabular form as shown below :

Observations

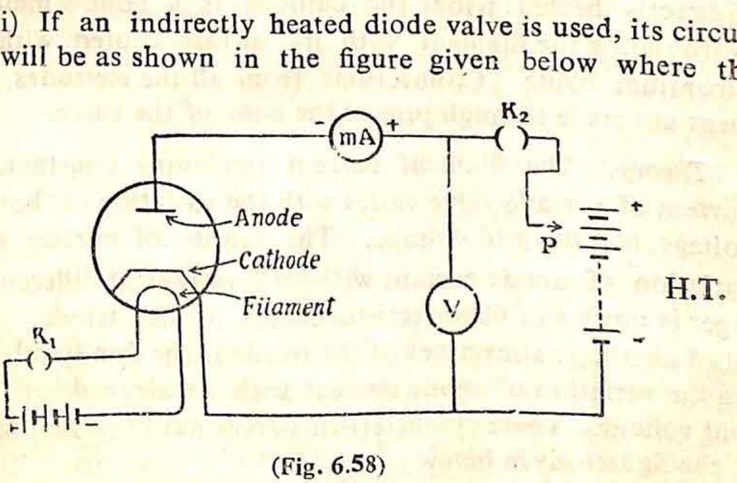
No. of observations	Filament current in mA	Plate current (I_a) in mA						
		$V_a=10$ V	$V_a=20$ V	......	......	.....	......	$V=200$ V
1								
2								
3								

Graph. Draw graphs with plate voltage V_a on x-axis and plate current I_a on y-axis keeping the origin at 0 – 0. Three curves for the three filament currents will be obtained.

Calculations and Results. Locate the straight portions on the three characteristic curves, and find the value of the a.c. resistance of the valve from the curve.

Conclusions. Draw your conclusions from the characteristic curves about the variation of plate current with plate voltage and filament current in the different portions of the characteristic curves.

Note. (i) If an indirectly heated diode valve is used, its circuit connection will be as shown in the figure given below where the



(Fig. 6.58)

filament is directly connected to a 6 volt battery or 6·3 V A.C. terminals of Power Pack because such a valve is generally operated at a filament voltage of 6·3 volts. 6·3 volts out-put may also be obtained from a.c. main by using a stepdown transformer. H.T. may also be available in the power pack.

(ii) In the absence of a diode, a triode may be converted into a diode by connecting the grid to the plate.

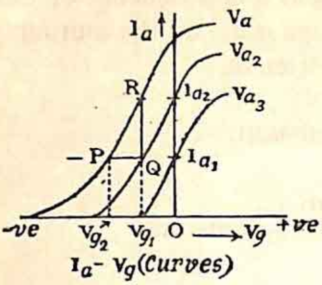
(iii) The point *P* on the H.T. should be the +ve terminals and not the −ve terminals of the H.T. battery or Power Pack.

EXPERIMENT 23. **To draw the characteristic curves of a triode valve and to determine its amplification factor, dynamic plate resistance, and mutual grid conductance.**

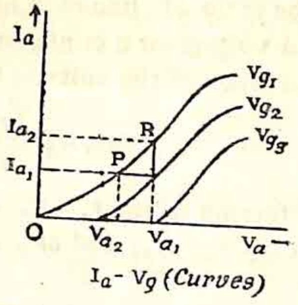
Apparatus. The triode valve, a milliammeter of 0—25 mA range, a voltmeter of 0—200 V range, a voltmeter of 0—6 V range, another milliammeter of 0—250 mA range, two rheostats; one of these being of about 20 Ω, a high tension (H.T.) battery or stabilised Power Pack of about 200 V (variable), two low tension batteries of 6 volts each (6·3 V A.C. terminals and D.C. Bias terminals are also sometimes available is a Power Pack, as in Fig. 6.62), and a Pohl commutator.

Description. TRIODE VALVE : A triode valve consists of three electrodes : the anode, the grid and the cathode placed in an evacuated enclosure of glass or metal. The cathode may be of directly heated type or indirectly heated type in which case a filament heats the cathode. The grid is in the form of a spiral of wire surrounding the cathode; and the anode is a hollow cylinder surrounding the grid. In a directly heated triode, cathode is the filament itself, but in an indirectly heated triode the cathode is a hollow metallic cylinder surrounding the filament with its surface coated with Barium or Strontium oxide. Connections from all the eletrodes, and the filament are made through pins at the base of the valve.

Theory. The filament current remaining constant, the anode current of a triode valve varies with the variation of both the anode voltage, and the grid voltage. The family of curves showing the variation of anode current with grid voltage at different anode voltages is one set of characteristic curves of the triode. The second set of characteristic curves of the triode is the family of curves showing the variation of anode current with anode voltage ot different grid voltages. These characteristic curves have the nature as shown in the figures given below :



(Fig. 6.59)



(Fig. 6.60)

The ratio of the change in anode voltage to the change in grid voltage needed to maintain the plate current constant is called the amplification factor, μ, of the valve. It may be written

$$\mu=\left(\frac{\delta V_a}{\delta V_g}\right) \text{ at } I_a \text{ constant.}$$

Referring the I_a-V_g curves for V_{a1} and V_{a2},

$\delta V_a=\delta V_{a1}-V_{a2}$ and $\delta V_g=V_{g1}-V_{g2}$ for current to remain constant at I_{a1}.

$$\therefore \quad \mu=\frac{V_{a1}-V_{a2}}{V_{g1}-V_{g2}}.$$

Referring to the I_a-V_a curves for V_{g1} and V_{g2},

$\delta V_a=V_{a1}-V_{a2}$ and $\delta V_g=V_{g1}-V_{g2}$ for current to remain constant at I_{a1}.

$$\therefore \quad \mu=\frac{V_{a1}-V_{a2}}{V_{g1}-V_{g2}}.$$

The ratio of the change in anode voltage to the consequent change in anode current, grid voltage remaining constant, is called the dynamic plate resistance of the valve. It may be written as

$$R_a=\left(\frac{\delta V_a}{\delta I_a}\right) \text{ at } V_g \text{ constant.}$$

Referring to the I_a-V_g curves for V_{a1} and V_{a2},

$\delta V_a=V_{a1}-V_{a2}$ and $I_a=I_{a2}-I_{a1}$ at constant $-V_{g1}$.

$$\therefore \quad R_a=\frac{V_{a1}-V_{a2}}{I_{a2}-I_{a1}}.$$

Referring to the I_a-V_a curves for V_{g1},

$\delta V_a=V_{a1}-V_{a2}$ and $\delta I_a=I_{a2}-I_{a1}$ at constant $-V_{g1}$.

$$\therefore \quad R_a=\frac{V_{a1}-V_{a2}}{I_{a2}-I_{a1}}.$$

The ratio of change in anode current as a consequence of change in grid voltage at a constant anode voltage is called the mutual grid conductance of the valve. It may be written as

$$gm=\left(\frac{\delta I_a}{\delta V_g}\right) \text{ at } V_a \text{ constant.}$$

Referring to the $I_a - F_g$ curves for V_{a1},
$\delta I_a = I_{a2} - I_{a1}$ and $\delta V_g = V_{g1} - V_{g2}$ at V_{a1} constant.

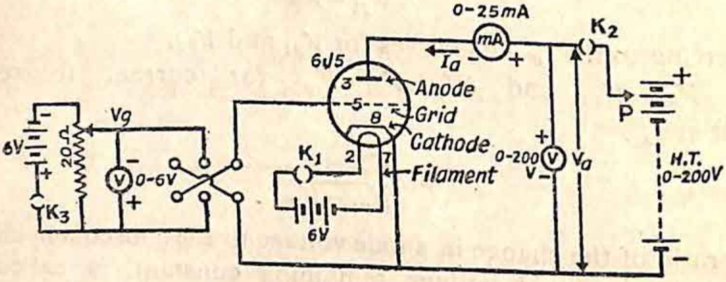
$$\therefore \quad gm=\frac{I_{a2}-I_{a1}}{V_{g1}-V_{g2}}.$$

Referring to the $I_a - V_a$ curves for V_{g1} and V_{g2},
$\delta I_a = I_{a2} - I_{a1}$ and $\delta V_g = V_{g1} - V_{g2}$ at V_{a1} constant.

$$\therefore \quad gm=\frac{I_{a2}-I_{a1}}{V_{g1}-V_{g2}}.$$

Theoretically,

$$\mu=\frac{\delta V_a}{\delta V_g}=\frac{\delta V_a}{\delta V_a}\times\frac{\delta I_a}{\delta V_g}=R_a\times gm.$$



(Fig. 6.61)

Procedure. (i) Carefully note the pins of the triode, and make circuit connections as shown in figure 6.61.

(ii) Now close K_1.

(iii) Now throw the rocker of the Pohl commutator on the right side to apply a negative potential on the grid with respect to the cathode. Plug in the key K_3. Adjust the rheostat to get a grid voltage of −5 volts. Connect the point P of the anode circuit to the positive terminal H. T. and adjust the H. T. to get an anode voltage of about 10 volts. Now plug in the key K_2, and note the grid voltage, anode voltage and anode current.

(iv) By further adjusting the H. T. in steps of 10 V, apply different potentials to the anode and note the plate currents for the different plate voltage while the grid voltage remains fixed.

(v) Now change the grid voltages to -4 volts by adjusting the rheostat and get another set of observations for anode voltages and anode currents.

(vi) Also get observations of anode voltages and anode currents at grid voltages of -3, -2, -1, and 0 volts.

(vii) Now throw the rocker of the Pohl commutator on the left, and get observations of anode voltages and anode currents at grid voltages of $+1$, and $+2$ volts.

(viii) Enter your observations in the table of the type shown below :

Observations

Grid Voltage (V_g)	Anode current Readings (I_a)						
	At $V_a=10$ V	At $V_a=20$ V	At $V_a=30$ V	At	At	At	At $V_a=200$ V
-5 V							
-4 V							
-3 V							
-2 V							
-1 V							
0 V							
$+1$ V							
$+2$ V							

Graphs. (i) *I_a—V_g graph.*

With V_g on x-axis, and I_a on y-axis draw curves for different values of V_a. The position of the y-axis should be properly chosen to allow for both +ve and —ve potentials of the grid to be taken on the x-axis. The origin of the graph should be $0-0$.

(ii) *$I_a - V_a$ graph.*

With V_a on x-axis and I_a on y-axis draw curves for different values of V_g, keeping the origin of the graph as $0-0$.

Calculations. Choose only the straight portions of the characteristic curves for the calculation of μ, R_a and gm. Use only those curves for the purpose of calculation that have a fairly large straight portion.

The method of calculating μ, R_a and gm have been described in the theory portion.

Results. $\mu = \ldots\ldots$

$R_a = \ldots\ldots\Omega$

$gm = \ldots\ldots$ mA/V

$= \ldots\ldots$ Mhos.

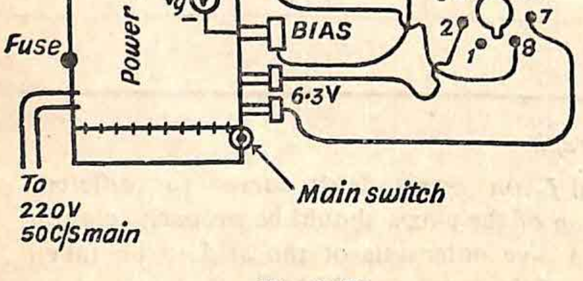
Check if $R_a \times gm$ is equal to the value of μ.

Note. (i) The experiment will be simplified by the use of an indirectly heated triode (say 6 J 5 type) as such valves normally operate directly with a source of 6·3 volts for the filaments. Hence a 6 V battery may be directly connected to the filament.

(ii) A grid voltage of more than +2 volts is not advisable as the valve may lose emission considerably at higher grid voltages.

(iii) The variable point P on the H. T. should be the +ve terminals and not the −ve terminals of the H.T.

(iv) In place of a H. T. battery a power pack run on an a.c. main may also be used. In several power packs apart from the facility of getting filament current at 6·3 V A.C. and H.T. voltages up to 300 volts, there are arrangements for getting D.C. negative grid biases also. To measure anode voltages and grid voltages, sometimes the power pack has suitable voltmeters internally connected. Some power packs also



(Fig. 6.62)

contain milliammeter to measure the anode current. As has been shown in the figure, the terminals of a power pack are marked as H. T.+, BIAS COMM., and 6·3 V. In the figure a scheme of connection with a 6 J 5 triode has been shown.

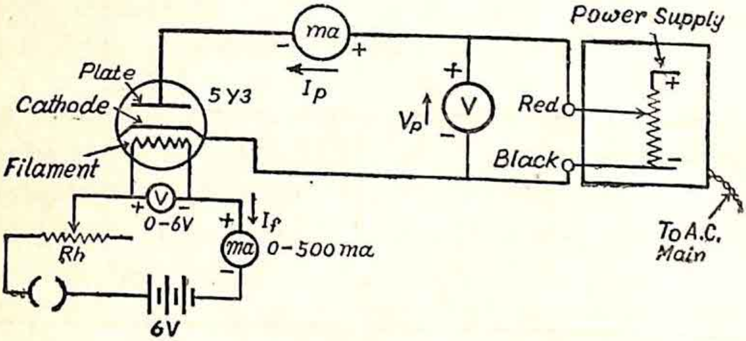
When using a Power Pack take readings at $V_g = 0, -1, -2, ..$etc., i.e, at zero and negative grid voltages.

EXPERIMENT 24. To verify 3/2 power law by a Diode.

Apparatus. Diode valve (may be 5 Y 3), stabilised power supply (0 – 300 volts), 6 V battery, 10 Ω rheostat, plug key, two milliammeters [one 0—500 ma and another 0—25 ma), voltmeters (0—300 V and 0 – 6 V).

Theory. The space change limited current of a diode is given by $I_p = KV_p^{3/2}$. Hence $\log_{10} I_p = \log_{10} K + \frac{3}{2} \log_{10} V_p$. Therefore $\log_{10} I_p$ against $\log_{10} V_p$ curve should be straight line of slope 3/2, if the 3/2 power law is true.

Procedure. (i) Make circuit connections as in the circuit diagram given below :



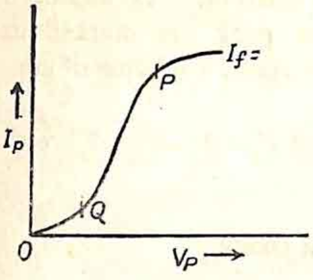
(Fig. 6.63)

(ii) Adjust the filament rheostat for 5 V filament voltage reading. Read the filament current, I_f.

(iii) Apply voltage from power supply from zero to 300 volts in steps of 20 volts or so (noting V_p), and note the plate current, I_p every time.

(iv) Adjust the filament rheostat so that the filament current becomes $\frac{3}{4}$ of the previous value, and take I_p observations against different V_p again.

(v) Draw the curves with I_p against V_p for the two I_f values.



(Fig. 6.64)

(vi) Choose the observations that are well below the saturation stage, but not corresponding to too small I_p values (i.e. choose points between P and Q of Fig. 6.64).

(vii) For every set of I_f, obtain $\log_{10} V_p$ and $\log_{10} I_p$ values from log-table.

(viii) Plot $\log_{10} I_p$ against $\log_{10} V_p$ and obtain the slope of the straight line graph.

Observations

Filament Current (I_f)	Plate Voltage (V_p)	Plate Current (I_p)	$\log_{10} V_p$	$\log_{10} I_p$

Results and Conclusion.

Slope of the $\log_{10} I_p$ vers. $\log_{10} V_p$ straight line = ...

Difference from 3/2 = ...

Percentage difference.......

Conclusions. Draw your conclusion from the experimental results.

Discussion. (i) The difference of the experimentally observed slope from $3/2 = 1{\cdot}5$ will be negligible.

(ii) The saturation part of the V_p—I_p curve is the situation of temperature limited emission, and so this should be left out. Space charge limited part falls below the saturation part.

(iii) For low V_p values, the slope differs from 3/2 on account of higher emission velocities, and so the portion of I_p against V_p curve corresponding to low V_p values should be left out.

Note. 1. If a diode valve is not available, a triode valve may be converted into a diode valve by connecting its plate and grid together.

2. 6 H 6 diode valve may also be used. It has two plates and two cathodes. The two plates and the two cathodes may be connected together.

EXPERIMENT 25. **To construct, calibrate, and use a Thermo-Electric Thermometer.**

Apparatus. Copper and iron wires, galvanometer, thermometer ($0° - 110°C$), two beakers, one funnel, hypsometer, ice, wax, and glass tube.

Theory. If the ends of two wires of different metals be joined together and if the two joints thus formed be maintained at different temperatures, then an electric current flows in the wires due to an e.m f. generated, known as the Sebeck e.m.f. Maintaining one junction at 0°C, if the temperature, t°C of the other junction is raised, the Sebeck e.m.f., E increases linearly over a wide range of temperature. Hence, a galvanometer may be placed in the circuit thus obtained, and its deflections may be calibrated against the temperatures of the hot junction to give a thermoelectric thermometer with which an unknown temperature may be measured.

Procedure. (i) Put one end of the copper wire and one end of iron wire together and get it welded. Likewise put the other end of the copper wire with the other end of the iron wire and get it welded.

(ii) Cut the copper-wire at the middle and connect the galvanometer to the two ends thus obtained. Set it to read zero.

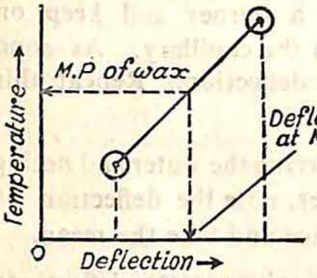
(iii) Put the two junctions of the wires in glass tubes with their lower ends sealed. You have now constructed a thermo-couple.

(iv) Put some crushed ice in a funnel mounted over a ring clamped to a stand, with its tail in a beaker.

(v) Insert the tube containing one of the junctions of the thermocouple in the ice, and clamp it with cork padding to a stand.

$$\left.\begin{array}{r}\text{Deflection at the melting of wax} = \left.\begin{array}{l}(1)\ldots\\(2)\ldots\\(3)\ldots\end{array}\right\}\text{Mean}\ldots\\[2ex] \text{Deflection at the solidification of wax} = \left.\begin{array}{l}(1)\ldots\\(2)\ldots\\(3)\ldots\end{array}\right\}\text{Mean}\ldots\end{array}\right\}\begin{array}{l}\text{Grand}\\\text{Mean} = \ldots\end{array}$$

Result. Melting point of wax from calibration graph = ...°C.



(Fig. 6.66)

Note. In this experiment maintaining various steady temperatures of water for the calibration of the thermoelectric thermometer is inconvenient. The water at the room conditions, and at the B.P. are steady thermal states. Hence, calibration of the thermoelectric thermometer against these two temperatures will be quite reliable.

EXPERIMENT 26. To measure the Inductance and Resistance of an Inductive Circuit by Ammeter and Voltmeter.

Apparatus. Inductance coil of about 0·1 H, resistance boxes (250 ma current capacity), A.C. voltmeter (0 – 10 V), A.C. ammeter (0 – 500 ma), switch, and Bell transformer.

Theory. A coil of inductance L and resistance r connected in series with a resistance R constitutes a circuit of impedance,

$$|Z| = \sqrt{(R+r)^2+\omega^2L^3}, \text{ where } \omega = 2\pi f,$$

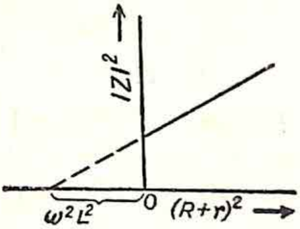
f being the frequency of the A.C. source connected in series with the circuit. If the r.m.s. values of e.m.f. applied and the current in the circuit be E and I respectively,

$$\frac{E}{I} = \sqrt{(R+r)^2+\omega^2L^2}$$

$$= |Z|.$$

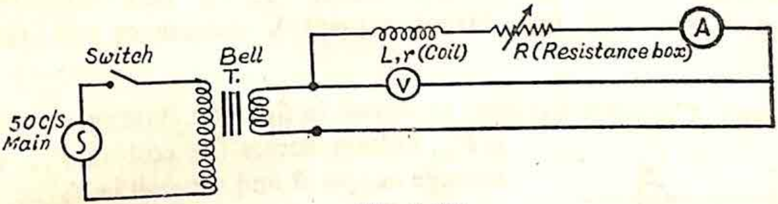
Measurement of E and I will, therefore, give $|Z|$; further $|Z|^2 =$

$(R+r)^2+\omega^2L^3$, and so the graph plotted with $|Z|^2$ against $(R+r)^2$ will be a straight line intercepting the $(R+r)^2$ axis at ω^2L^2. From this intercept and from $\omega=2\pi f$, the inductance L of the circuit can be calculated. The resistance of the coil, r, may be determined by P.O. box, and it may be ignored in case it is small (say 2 Ω or so) in comparison to R (say 50 Ω or above).



(Fig. 6.67)

Procedure. (i) Make circuit connections as given in the circuit diagram below—



(Fig. 6.68)

(ii) Measure the d.c. resistance r, of the inductance coil by P.O. box by taking out the coil from the circuit.

(iii) Insert the coil again in the circuit. Take a resistance of 50 Ω in R. Press the switch of the main and read A and V to give I and E respectively.

(iv) Increase R in steps of 20 Ω and read A and V.

(v) Calculate $|Z|^2$ and $(R+r)^2$ corresponding to the different values of R.

(vi) Plot $|Z|^2$ against $(R+r)^2$, and obtain a straight line graph.

Observations

r by P.O. Box$=\ldots.\Omega, f=50$ C/s

No. of obs.	R	$(R+r)^2$	E	I	$\|Z\|=\frac{E}{I}$	$\|Z\|^2$
1						
2						
...						
...						
...						
..						
10						

Result. ω^2L^2 from graph = ...

$\omega = 2\pi f =$ . . . . . ., $\omega^2 =$ . . . . . .

$\therefore$ $L^2 =$ . . . . . ., and $L =$ . . . . . .H.

Note. As indicated in theory, if r be small compared to R, graph may be plotted with $|Z|^2$ against R^2 to obtain ω^2L^2. A coil of inductance up to 0·1 H may fulfil this condition when R is above 50 Ω.

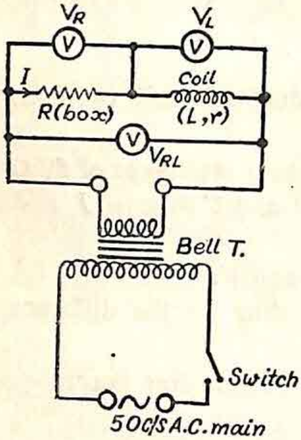
EXPERIMENT 27. To determine L and R in an A.C. circuit by three voltmeters method.

Apparatus. Three A.C. voltmeters (0 – 12 V), Bell transformer, resistance box (250 ma current capacity), inductance coil (nearly 0·1 H).

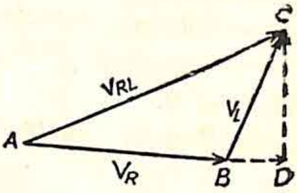
Theory. Consider a circuit as shown in fig. 6.69. Voltage across R is V_R, voltage across the coil is V_L, and voltage across R and the coil is V_{RL}.

These voltages are vectorially shown in fig. 6.70.

$$V_R = I_R = AB.$$



(Fig. 6.69)



(Fig. 6.70)

Let r be the resistance of the inductance coil. Ir is then the voltage drop over the coil due to its resistance and it is in phase with $\vec{AB}$, represented by $\vec{BD}$. Voltage drop over the coil due to its reactance ωL is $I\omega L$ and it will differ in phase by $\pi/2$ with the voltage drop due to r. Hence, it is represented by $\vec{DC}$, perpendicular to $\vec{BD}$. The vector sum of $\vec{BD}$ and $\vec{DC}$ is $\vec{BC}$ which represents the voltage drop over the coil, V_L. The vector sum of $\vec{AB}$ and $\vec{BC}$ is $\vec{AC}$ which represents voltage drop across R and the coil, V_{RL}.

As $IR=AB$, $Ir=BD$, and $I\omega L=DC$, we have

$$r=R\frac{BD}{AB}, \text{ and } L=\frac{R}{\omega}\ \frac{DC}{AB}=\frac{R}{2\pi f}\ \frac{DC}{AB},$$

where f is the frequency of the source.

By measurement of V_R, V_L, and V_{RL} the voltage vector triangle can be drawn, and from the triangle, BD and DC can be determined; $AB=V_{RL}$ and $f=50$ C/s, and hence r and L of the coil becomes determinable.

Procedure. (i) Make circuit connections as shown in Fig. 6 69.

(ii) Take a coil of about 0·1 H, and keep $R=100\ \Omega$. Switch on the main and note the readings of the three voltmeters.

(iii) Increase R in steps of 20 Ω and every time read the three voltmeters after switching on the main. Take five observations.

(iv) Draw voltage triangle on a graph paper for every observation to determine AB, BD and DC.

(v) From every set determine the value of L and r, and find their mean values.

Observations

$f=50$ C/s

No. of obs.	R	V_R	V_L	V_{RL}	AB	BD	DC	L	r
1									
2									
3									
4									
5									

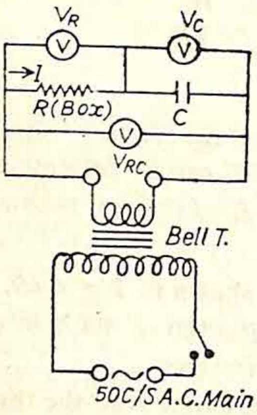
Result. Mean L of the coil = ...H

Mean r of the coil = ...Ω.

EXPERIMENT 28. **To determine the *C* and *R* in an A. C. circuit by three voltmeters method.**

Apparatus. Three A.C. voltmeters (0 – 12 V), Bell transformer, resistance box (250 ma current capacity), condenser (nearly 2 μF).

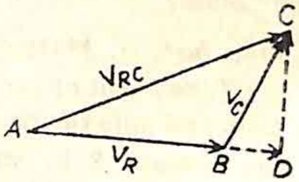
Theory. Consider a circuit shown in Fig. 6.71.



(Fig. 6.71)

Voltage across R is V_R, voltage across the condenser is V_C, and the voltage across R and the condenser is V_{RC}. Their voltages are vectorially shown in Fig. 6.72.

$$V_R = IR = AB.$$



(Fig. 6.72)

The vector sum of V_R and V_C will be V_{RC}, and so $\vec{BC}$ and $\vec{AC}$ will represent V_C and V_{RC} respectively in the vector triangle. If there is no leakage in the condenser there will be a phase difference of $\pi/2$ between V_R and V_C. so that $\vec{BC}$ will be normal to $\vec{AB}$. In case of a loss resistance, r, associated with the condenser, $\vec{BC}$ will be the vector sum of a voltage in phase with V_R and another voltage differing in phase by $\pi/2$. These are represented by $\vec{BD}$ and $\vec{DC}$ and are easily obtained after drawing the vector triangle.

As $IR = AB$, $Ir = BD$, and $\dfrac{I}{\omega C} = DC$, we have $r = R\dfrac{BD}{AB}$, and

$C = \dfrac{1}{\omega R}\dfrac{AB}{DC} = \dfrac{1}{2\pi f R} \times \dfrac{AB}{DC}$, where f is the frequency of the source.

By measurement of V_R, V_C, and V_{RC} the voltage vector triangle can be drawn. From the triangle, BD and DC can be determined. $AB = V_{RC}$, $f = 50$ C/s, and hence r and C of the condenser becomes determinable.

Procedure. (i) Make circuit connections as shown in the Fig. 6.71.

(ii) Take a condenser of $C \approx 2\ \mu\text{F}$ and keep $R = 500\ \Omega$ and note he reading of the three voltmeters after switching on the main.

(iii) Increase R in steps of 100 Ω and every time read the three oltmeters after switching on the main. Take at least five observa-ions.

(iv) Draw voltage triangle on a graph paper for every observation to determine AB, BD and DC.

(v) From every set determine the value of C and r, and find the mean values.

Observations

$f = 50$ C/s.

No. of obs.	R	V_R	V_C	V_{RC}	AB	BD	DC	C	r
1									
2									
3									
4									
5									

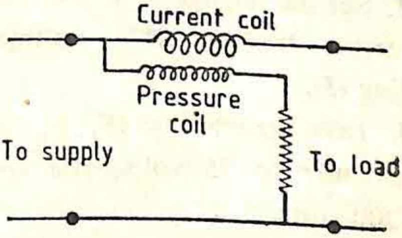
Result. Mean C of the condenser = ...μF.
Mean r of the condenser = ...Ω.

Note. Measurements may be made on two condensers of nearly same C, but having different di-electrics. This will provide an idea about the difference in loss-factors due to the di-electrics.

EXPERIMENT 29. **To measure the power factor of an A.C. fan by wattmeter.**

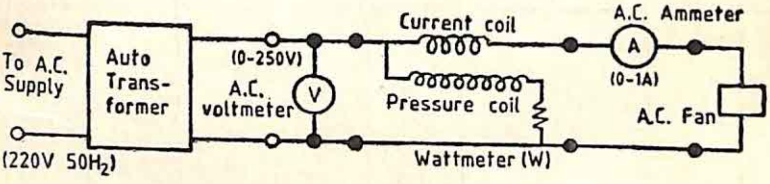
Apparatus. Wattmeter, A.C. ammeter, A.C. voltmeter, auto-transformer, and an A.C. fan.

Description. WATTMETER : This has a current coil which carries the load current, and a pressure coil which carries a current proportional to, and in phase with, the voltage. The mechanical force between the two coils, and hence the deflection of the pointer of the instrument is proportional to the product of the current in them and the power factor of the load. Thus the wattmeter measures the true watts absorbed in the load.



(Fig. 6.73)

Theory. If an A.C. voltage of V volts is applied to an A.C. fan, and if a current I amperes flows through it, then the true power absorbed by the fan is, $W=VI\cos\theta$ watt, where $\cos\theta$ is the power factor of the fan, θ beaing the phase angle between V and I. The wattmeter measures W.



(Fig. 6.74)

An A.C. ammeter measures just I and an A.C. voltmeter measures just V, so that VI is the apparent power only.

$$\text{Then, power factor}=\frac{\text{true power}}{\text{apparent power}}=\cos\theta.$$

Procedure. **1.** Make the circuit connections as shown in the figure given above.

2. Set the auto-transformer to give a reading of $V=50$ volts to start with.

3. Set the regulator of the fan to "slow" position. Take the wattmeter reading (W), voltmeter reading (V), and ammeter reading (I).

4. Take the readings W, V, and I at the settings of the auto-transformer to 75 volts, 100 volts, 125 volts, 150 volts, 175 volts, and 200 volts.

5. Repeat the above observations for the "medium" position and then for the "fast" position of the regulator of the fan.

Observations

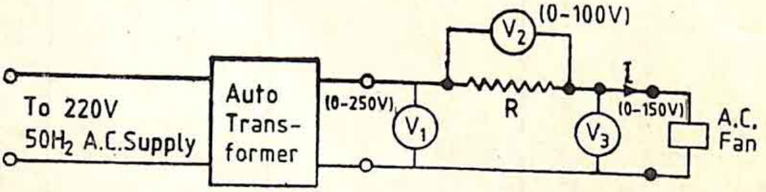
Position of the fan regulator	V in volts	I in Amps.	W in Watts	$V \times I$	Power Factor	Mean Power Factor
Slow	50					
	75					
	⋮					
	200					
Medium	50					
	75					
	⋮					
	200					
Fast	50					
	75					
	⋮					
	200					

Conclusion. It will be found that the power factor for a good A.C. fan is not less than 0·9. It decreases as the speed of the fan decreases.

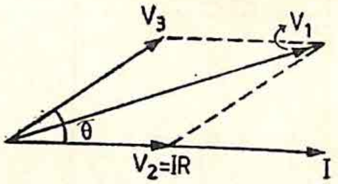
EXPERIMENT 30. To measure the power factor of an A.C. Fan by three voltmeters.

Apparatus. 3 A.C. voltmeters, a non-inductive resistance ($R=100\ \Omega$), an auto-transformer, and an A C. fan.

Theory. With the circuit connections as shown in the figure given below, we have $V_1^2=V_2^2+V_3^2+2V_2V_3\cos\theta$.



(Fig. 6.75)



(Fig. 6.76)

As

$$V_2=IR,$$
$$V_1^2=V_2^2+V_3^2+2IRV_3\cos\theta$$

$$\therefore \quad IV_3\cos\theta=\text{Power in the fan}=\frac{V_1^2-V_2^2-V_3^2}{2R}$$

and
$$\cos\theta=\frac{V_1^2-V_2^2-V_3^2}{2RIV_3}=\frac{V_1^2-V_2^2-V_3^2}{2R\frac{V_2}{R}V_3}=\frac{V_1^2-V_2^2-V_3^2}{2V_2V_3}.$$

Procedure. 1. Make circuit connections as shown in the figure given above.

2. Set the auto-transformer to give a reading of $V_1=50$ volts to start with.

3. Set the regulator of the fan to "slow" position. Take the voltmeter readings V_1, V_2 and V_3.

4. Take the readings V_1, V_2 and V_3 at the settings of the auto-transformer to 75 V, 100 V, 125 V, 150 V, 175 V, and 200 V.

5. Repeat the above observations for the "medium" position and then for the "fast" position of the regulator of the fan.

Observations

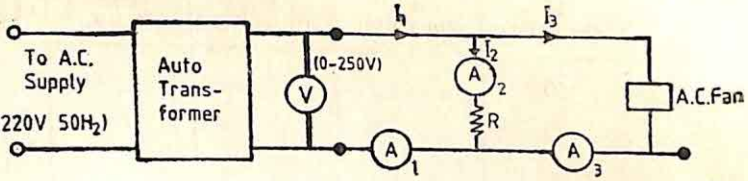
Position of the Fan regulator	V_1 (in volts)	V_2 (in volts)	V_3 (in volts)	Power factor	Mean Power factor
Slow	50				
	75				
	⋮				
	200				
Medium	50				
	75				
	⋮				
	200				
Fast	50				
	75				
	⋮				
	200				

Conclusion. It will be found that the power factor of a good A.C. fan is not less than 0·9. It decreases as the speed of the fan decreases.

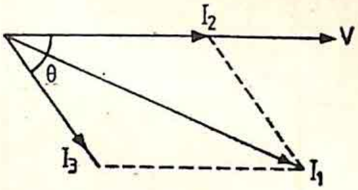
EXPERIMENT 31. **To measure the power factor of an A.C. Fan by three ammeters.**

Apparatus. A voltmeter, 3 A.C. ammeters, a non-inductive resistance ($R = 100\ \Omega$), an auto-transformer, and an A.C. fan.

Theory. With the circuit connections as shown in the figure given below, we have $I_1^2 = I_2^2 + I_3^2 + 2I_2\, I_3 \cos\theta$



(Fig. 6.77)



(Fig. 6.78)

As $I_2 = \frac{V}{R}$,

$$I_1^2 = I_2^2 + I_3^2 + 2\frac{V}{R} I_3 \cos\theta$$

$$\therefore \quad I_3 V \cos\theta = \text{Power in the fan} = \frac{(I_1^2 - I_2^2 - I_3^2)R}{2}$$

and $$\cos\theta = \frac{(I_1^2 - I_2^2 - I_3^2)R}{2I_3 V} = \frac{(I_1^2 - I_2^2 - I_3^2)R}{2I_3 I_2 R} = \frac{I_1^2 - I_2^2 - I_3^2}{2I_3 I_2}.$$

Procedure. **1.** Make circuit connections as shown in the figure given above.

2. Set the auto-transformer to give a reading of $V = 50$ volts to start with.

3. Set the regulator of the fan to "slow" position. Take the readings of the ammeters A_1 A_2 and A_3, and let these be I_1, I_2 and I_3 respectively.

4. Take the readings of the ammeters A_1, A_2 and A_3 at the settings of auto-transformer to 75 V, 100 V, 125 V, 150 V, 175 V and 200 V.

5. Repeat the above observations for the "medium" position, and then for the "fast" position of the regulator of the fan.

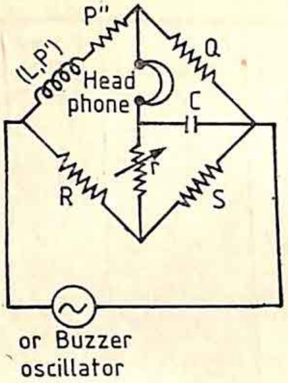
Observations

Position of the Fan regulator	V (in volts)	I_1 (in amps.)	I_2 (in amps.)	I_3 (in amps.)	Power factor	Mean Power factor
Slow	50					
	75					
	⋮					
	200					
Medium	50					
	75					
	⋮					
	200					
Fast	50					
	75					
	⋮					
	200					

Conclusion. It will be found that the power factor for a good A.C. fan is not less than 0 9. It decreases as the speed of the fan decreases.

EXPERIMENT 32. To measure the inductance of a coil by Anderson's Bridge.

Apparatus. Five non-inductive resistance boxes, a capacitance box with capacitances in units and fraction of unit micro-farad, inductance coil, a head-phone, an A.C. source (L.F. oscillator of 1 KHz) or a buzzer.



(Fig. 6.79)

Theory. The scheme of an Anderson's Bridge is as shown in the given figure. The coil has an inductance L and resistance is P'.

The conditions of balance (no sound in the head-phone) are

(i) $P/Q = R/S$,

where $P = P' + P''$ and

(ii) $L = CQ\,[R + r(1 + \frac{P}{Q})]$.

When $P/Q = 1$,

$$L = CQ[R + 2r].$$

For the bridge to be sensitive,

$$S = R = \tfrac{1}{2}P = \tfrac{1}{2}Q$$

and $$\frac{L}{C} = 2P^2.$$

A.C. balance is possible only when $L > CRQ$.

Procedure. 1. Set up the bridge as shown in the figure.

2. Keep $R = S = 10\ \Omega$, and $P'' = Q = 2R = 2S = 20\ \Omega$.

3. As $2P''^2 = 800$, making a guess for L to be of the order of, say, a few mH, C will have to be kept at about 1 μF for the sensitiveness of the bridge. Start with $C = 1$ μF. This will satisfy the condition that $L > CRQ$.

4. Now adjust P'' for a minimum sound in the head-phone. You may get the minimum in a range of P'' values. Take the mean of this range as the values of P''. Then keeping P'' at this value adjust r for a minimum of sound in the head-phone. You may get minimum sound in a range of r values. Take the mean of this range as the value of r. Calculate L using the above values of r.

5. Substitute this L in $C = \frac{L}{2P''^2}$, and calculate C using the above value of P''. Make C nearly equal to this calculated value of C.

6. Again adjust P'' for minimum sound in the head-phone and then r to further minimise the sound. Calculate L again.

7. Repeat the operation 6 for a few more values of C until the sound in the head-phone is minimum over as narrow a range of r as possible.

Observations

No. of obs.	P'' in Ω	Q in Ω	S in Ω	R in Ω	C in μF	r in Ω	L in H
1	20	20	10	10	1·0	115	0·0048
2	18	20	10	10	0·8	140	0·0046
3	17	20	10	10	0·7	155	0·0045

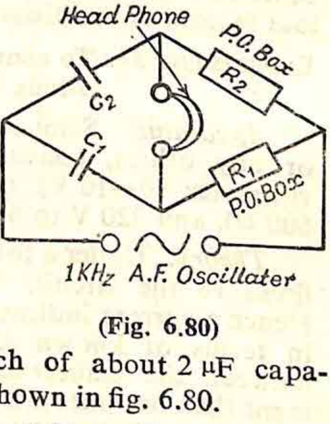
Result. The inductance, L of the coil

$$=0{\cdot}0045\ \text{H}=4{\cdot}5\ \text{mH}.$$

EXPERIMENT 33. **To compare two capacities by De Santy's Bridge.**

Apparatus. Two condensers, two P. O. boxes, 1 KHz oscillator or buzzer, a head-phone.

Theory. A Wheatstone bridge is set up with the two condensers in two adjecent arms, and two P.O. boxes in the other two arms as shown in fig. 6.80 is known as De Santy's bridge. The condition of balance of the bridge is given by $\frac{C_1}{C_2}=\frac{R_2}{R_1}$. The bridge is sensitive when C_1 and C_2 are appoximately equal, and large.



(Fig. 6.80)

Procedure. (i) Take two condensers each of about 2 μF capacitance, and set up a De Santy's bridge as shown in fig. 6.80.

(ii) Make $R_1=1000\ \Omega$, and switch on the A.F. oscillator.

(iii) Put the speakers of the head-phone on your head. You will hear a sound. Adjust R_2 till you have a minimum sound; note this R_2.

(iv) Keeping $R_1=1500\ \Omega$, $2000\ \Omega$, $2500\ \Omega$ and $3000\ \Omega$ one by one, adjust R_2 to get minimum sound. Note the values of R_2.

(v) Calculate C_1/C_2 from your observations and find the mean C_1/C_2.

(vi) Compare this value with the C_1/C_2 as calculated from the individual values of C_1 and C_2 written on the condensers.

Observations

No. of obs.	R_1	R_2	$C_1/C_2=\frac{R_2}{R_1}$	Mean C_1/C_2
1	1000 Ω			
2	1500 Ω			
3	2000 Ω			
4	2500 Ω			
5	3000 Ω			

Result. C_1/C_2 by experiment = ...
C_1 as written on the condenser = ...
C_2 as written on the condenser = ...
C_1/C_2 from the values of C_1 and C_2 = ...

Percentage difference between observed C_1/C_2 and calculated C_1/C_2 = ...

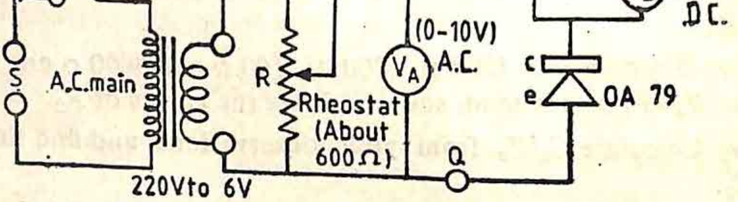
Note. The dielectrics of the two condensers should be the same, otherwise the bridge will be insensitive due to the difference in the loss factors of the dielectrics.

EXPERIMENT 34. **To construct and calibrate an A.C. semi-conductor Diode Voltmeter.**

Apparatus. Semi-conductor diode valve (0 A 79 or 05—SMI or any other), condenser (8 μF), A. C. voltmeter (0 – 10 V), D.C. voltmeter (0—10 V) range and high resistance rheostat (about 600 Ω), and 220 V to 6 V step-down transformer.

Theory. Under a forward bias the diode conducts and a current flows in the circuit. Under a backward bias, no current flows. Hence a current indicating device in the circuit may be calibrated in terms of known A. C. or D. C. potential differences applied between the emitter and the collector of a diode. Such an arrangement then becomes a Diode Voltmeter.

Procedure. (i) Make circuit connections as shown in fig. 6.81.



(Fig. 6.81)

(ii) After bringing the slide in contact of R to a lower point, switch on the main. Adjust the slide of R obtaining 1 V reading in V_A.

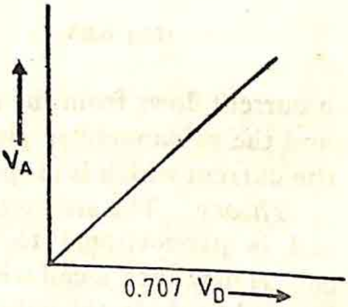
(iii) As the resistance of voltmeter V_D is high, and C is also high, the RC circuit of the diode will have high time constant. The rectified current from the diode valve charges C up to the peak voltage of the applied A.C. This steady D.C. voltage is recorded by the D.C. voltmeter V_D. Note the voltage as indicated by V_D and multiply it by $\frac{1}{\sqrt{2}}=0{\cdot}707$ to give the R.M.S. value of the A.C. voltage.

(iv) Increase the applied A.C. voltage by I V, step by step up to 6 V by adjusting the slide of the rheostat R and keep on noting voltmeters V_A and V_D.

(v) Multiply all readings of the voltmeter V_D by 0·707, draw a gragh with V_A against $0{\cdot}707\ V_D$. This will be calibration curve of the Diode Voltmeter on the left of PQ (Fig. 6.82).

(vi) Find the slope of the $V_A-0{\cdot}707\ V_D$ curve.

(v) Also find out the difference between V_A and $0{\cdot}707\ V_D$.



(Fig. 6.82)

Observatians

No. of obs.	R.M.S., A.C. voltage V_A	D.C. voltage V_D	$0{\cdot}707\ V_D$	$V_A-0{\cdot}707V_D$
1				
2				
:				
:				
10				

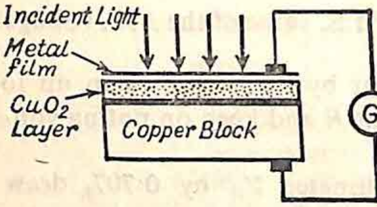
Result. Slope of $V_A-0{\cdot}707\ V_D$ graph= .....
Mean difference, $V_A-0{\cdot}707\ V_D$= .....

Comments. You may conclude from the results that the R.M.S. to the peak values of an A.C. voltage is $\frac{1}{\sqrt{2}}$.

EXPERIMENT 35. To study the Directional Variation of Light Intensity of Electric Bulb with a Photocell.

Apparatus. Photo voltaic cell, turn table, index with clamp, bulbholder, bulb, graduated annular plastic disc, clamp and stand, Weston galvanometer.

Description of Special Apparatus. PHOTOVOLTAIC CELL : It (fig. 6.83) consists a copper block with its upper layer oxidised to Cu_2O state, having a thickness of 10 μ. There is a transparent metal-film (platinum film) over the oxide layer. One terminal for cell is attached to the metal block and the other to the metal film. Light is made to fall over the metal film. Electrons released by the Cu_2O pass to the copper block, and thus a current flows from the metal film to copper in the external circuit and the galvanometer gives indication as well as the strength of the current which is proportional to the intensity of the incident light.



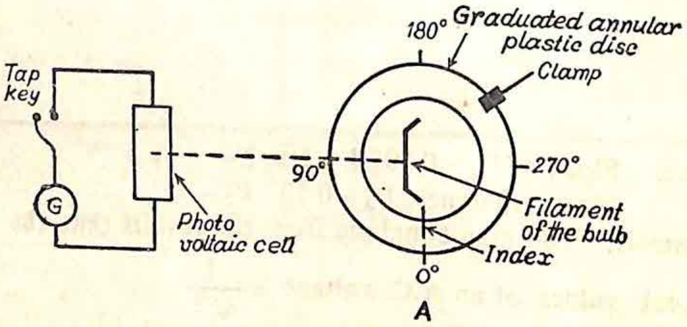
(Fig. 6.83)

Theory. The strength of the current given by a photovoltaic cell is proportional to the intensity of the light incident over the cell. Hence such a cell with a galvanometer in its external circuit can be used to study the light intensity of a bulb in various directions.

Procedure. (i) Put the bulbholder vertically on the turntable, and insert the bulb in it.

(ii) With the help of the clamp and stand arrange the annular graduated plastic disc with its centre at the centre of the filament of the bulb.

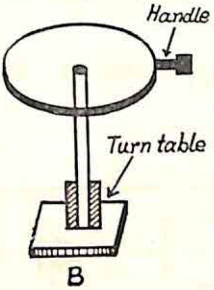
(iii) Fix the index with the clamp to the bulbholder so that it goes over the graduated annular disc and it is along the length of the filament of the bulb.



[Fig 6.84 (A)]

(iv) Arrange the photovoltaic cell on a stand of suitable height so that the centre of its face is at the same height as the height of the filament of the bulb.

(v) Connect the photovoltaic cell to a sensitive galvanometer with a tap-key.



[Fig. 6.84 (B)]

(vi) Switch on the bulb and close the tap-key to see if the galvanometer gives a good deflection. If not, adjust the position of the photovoltaic cell to get a good galvanometer deflection.

(v) Starting from 0° index reading rotate the turntable in state of 10° up to 360°, and go on noting the galvanometer deflection after closing the tap-key.

(vi) Plot the galvanometer deflection again the index reading preferably on a polar graph paper, or a Cartesian graph paper. This gives the directional variation of the light intensity of the bulb.

Observations

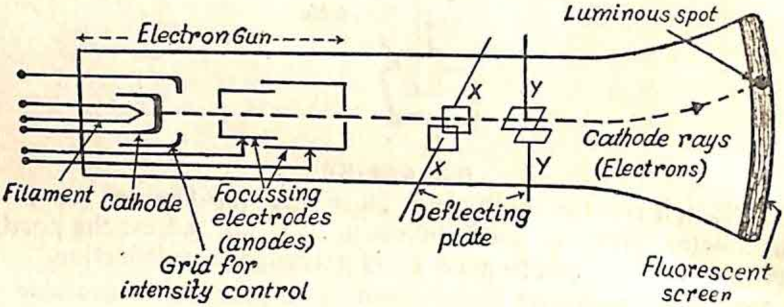
Index rod reading (θ)	Deflection of *G* (α)
0°	
10°	
...	
...	
360°	

Result. Draw your conclusions from the graph about the variation of light intensity with orientation of the length of the filament.

EXPERIMENT 36. **To use an Oscilloscope [CRO] for study of Waveform.**

Apparatus. Low frequency cathode ray oscilloscope, audio frequency oscillator, and a valve tube voltmeter or a solid state voltmeter.

Description of Special Apparatus (*i*) CRO. (Fig. 6.85)



(Fig. 6.85)

A CRO has three important parts: Electron gun, Deflecting plates, and Fluorescent screen. All these are housed in a long evacuated tube having one end spread in the form of a horn. The inner surface of this end is painted with some fluorescent powder.

The electron gun has a filament which is electrically heated. This heats the cathode which emits electrons. These emitted electrons (also called cathode rays) are accelerated and focussed into a narrow beam by two focussing electrodes maintained at higher potentials with respect to the cathode. The strength of the electron-beam-current is controlled by another electrode called the grid placed between the cathode and the focussing electrodes and maintained at a potential below the potential of the cathode. When the focussed beam of the electrons collides with the fluorescent screen, a luminous spot is produced over it.

Potential differences applied across two pairs of plates, *X—X* and *Y—Y* plates, deflect the electron beam in horizontal and vertical directions respectively. As an electron has extremely low mass, the electron beam will oscillate along the *X—X* direction or the *Y—Y* direction when an oscillating potential difference is applied on the *X—X* plates or the *Y—Y* plates.

A complete CRO equipment has the following components :

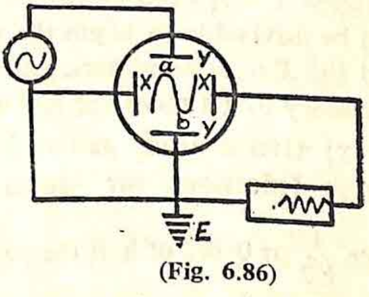
(1) CRO tube, (2) Amplifiers for vertical and horizontal deflection voltage, (3) Sweep generator to apply voltage across the $X-X$ plate to sweep the beam horizontally on the fluorescent screen, (4) The following controls, switches and terminals :

(a) Horizontal positioning control for the spot, (b) Vertical positioning control for the spot, (c) Focussing control, (d) Intensity control, (e) Internal and external synchronisation change over switch, (f) External and Internal $X-X$ (horizontal) input change over switch, (g) $Y-Y$ (vertical) input control, (h) $X-X$ input control, (i) External $X-X$ input terminals, (j) Synchronising amplitude control, (k) Coarse sweep frequency control, (l) Fine sweep frequeney control, (m) CRO on-off switch, (n) $Y-Y$ amplifier on-off switch, and (o) $X-X$ amplifier on-off switch.

(ii) *A. F. Oscillator.* A Laboratory A. F. Oscillator is a phase-shift oscillator of good frequency stability. It has a variable output. The A. F. obtainable is divided into three ranges. In each range frequency is adjusted by a calibrated rotary control.

(iii) VTVM *or Solid State Voltmeter*. In this instrument normally a low A.C. voltage is amplified first and then rectified. Sometimes the rectified D.C. voltage is subjected to D.C. amplification and then applied to a D.C. voltmeter. The voltmeter is calibrated to read the R.M.S. value of the voltage applied at the input. A selector switch helps in measuring voltages of different ranges.

Theory. The sweep voltage across the $X-X$ plates sweeps the electron beam of the CRO due to an extremely small innertia of the beam. This gives a horizontal trace on the screen of the CRO. An A.C. voltage applied across the $Y-Y$ plates will oscillate the beam up and down. When the $X-X$ voltage frequency and $Y-Y$ voltage frequency are equal or in integral multiples, a steady pattern of the $Y-Y$ voltage wave form is obtained on the CRO screen (Fig. 6.86). The crest (a) to trough (b) deflection of the beam as seen on the screen is proportional to twice the peak value of A.C. voltage and the number of complete voltage waves as observed on the screen is equal to the ratio of the frequency of the A.C. voltage across $Y-Y$ plates to the frequency of the $X-X$ sweep voltage.



(Fig. 6.86)

Procedure. (i) First study the panel of the CRO box and identify all the controls, switches, and terminals as mentioned in the description of CRO.

(ii) Connect the CRO to the main, and switch it on by putting the on-off switch to on-position.

(iii) After some time a spot will appear on the screen. Focus the spot sharply by the focus control. Also using the intensity control make the spot moderately intense. Position the spot at the centre of the CRO screen by using the vertical and horizontal positioning controls.

(iv) Use the coarse sweep frequency control to apply the sweep voltage on $X-X$ plates. The spot will now trace a straight line horizontally.

(v) Connect the A. F. oscillator out-put to the $Y-Y$ terminals and the VTVM or solid state voltmeter across it. Switch on the oscillator and adjust its voltage to about 1 volt and frequency to about 1 KHz.

(vi) You will get an unsteady waveform on the CRO screen. Adjust the coarse sweep frequency control until the waveform is nearly steady and then use the fine sweep frequency control to further steady the waveform.

(vii) Bring the synchronisation selector to internal position and adjust the synchronisation amplitude control to lock the waveform in steady condition.

(viii) In case you find that the vertical deflection or horizontal sweep is rather too much or too small, use vertical or horizontal input control, as necessary, to bring down or up the vertical deflection or horizontal sweep within the limits required.

(ix) In case the inputs to the $Y-Y$ or the $X-X$ plates are too much you may even switch off the $Y-Y$ or the $X-X$ amplifiers. It will be advisable to begin the work without switching on the $Y-Y$ and the $X-X$ amplifiers, and switch them on only as and when necessary to get more vertical and horizontal deflections.

(x) After a steady pattern has been obtained, measure the peak to trough deflections for inputs of 0·5 V, 1 V, 1·5 V, 2·0 V. Take $\frac{1}{\sqrt{2}}$ or 0·707 of half the peak to trough deflection, and plot it against the voltmeter reading. This calibration turns the CRO into a voltmeter.

(xi) Change the frequency of the generator to 10 KHz. Obtain a steady waveform again, and repeat the observations.

Observations

Frequency	Input volts $=V$	Peak to trough deflection	0·707 of half the peak to trough deflection $=d$
1 KHz	0·5		
	1·0		
	1·5		
	2·0		
10 KHz	0·5		
	1·0		
	1·5		
	2·0		

Result. Slope of the $V-d$ curve (straight line), at 1 KHz$=$....
Slope of the $V-d$ curve (straight line), at 10 KHz$=$....

Caution. Do not make the spot too intense for long time, otherwise it will cause permanent damage to the CRO screen.

Attention. The $Y-Y$, and the $X-X$ amplifier switches are usually situated at the back of the CRO box.

□□□

APPENDIX

1. Constants and Formulae

$\pi=3{\cdot}1416$, $\pi^2=9{\cdot}8696$, $\frac{1}{\pi}=0{\cdot}3183$

$e=2{\cdot}7183$, $\log_e 10=2{\cdot}3026$

$\sqrt{2}=1{\cdot}414$, $\sqrt{3}=1{\cdot}732$

Area of a circle $=\pi r^2$, Area of an ellipse $=\pi ab$ (Semi-axes a and b)
(of radius r)

Circumference of a circle $=2\pi r$
(of radius r)

Surface area of a sphere $=4\pi r^2$
(of radius r)

Volume of a Sphere $=\frac{4}{8}\pi r^3$,
(of radius r)

Volume of a Cylinder $=\pi r^2 h$
(of height h, and Cross-sectional radius r)

Volume of a cone $=\frac{1}{3}\pi r^2 h$.

2. Moment of Inertia

Rectangular bar of sides a and b, and mass M.	About an axis through the C. G. and perpendicular to the face containing a and b.	$M\frac{a^2+b^2}{12}$
Circular plate of radius r, and mass M.	About an axis through the centre and perpendicular to the plane of the plate.	$M\frac{r^2}{2}$
Solid sphere of radius r, and mass M.	About an axis through the diameter.	$\frac{2}{5}Mr^2$
Solid cylinder of radius r, length l, and mass M.	(i) About the axis of the cylinder	$M\frac{r^2}{2}$
	(ii) About an axis through the C. G. and perpendicular to the axis of the cylinder.	$M\left(\frac{l^2}{12}+\frac{r^2}{4}\right)$

3. Densities of Solids and Liquids (at 0°C) in gm./c.c.

Substance	Density	Substance	Density	Substance	Density	Substance	Density
Aluminium	2·70	Ice	0·916	*Silver*	10·5	*Milk* (Cow's)	1·03
Brass	8·4	Rubber	0·91—0·93	*Steel*	7·7—7·9	*Mobil oil*	0·91
Charcoal	1·4—1·5	*Iron* Pure	7·87	*Sugar*	1·39	*Olive oil*	0·91—0·93
Copper	8·93	Cast	7·0—7·6	*Wax*	0·95—0·96	*Turpentine*	0·87
Copper Sulphate Crystals	2·28	Wrought	7·7—7·9			*Xylene*	0·87
		Lead	11·37	*Wood* Teak	0·70—0·95		
Cork	0·18—0·26	*Paraffin*	0·87—0·96				
		Platinam	21·50	*Aniline*	1·035		
German Silver	8·3—8·9	*Salt*		*Glycerine*	1·260		
		Common	2·17	*Kerosene Oil*	0·91—0·93		
		Rock	2·28—2·41				
Glass :							
Crown	2·4—2·6	*Sand*	2·5	*Mercury*	13·596		
Flint	2·9—4·5						
Gold	19·32						

4. Density of Gases at N. T. P.

Air	0·001293	Nitrogen	0·001251
Carbon dioxide	0·001977	Oxygen	0·001429
Hydrogen	0·000090	Water Vapour	0·000814

5. Density of Water from 0°C to 100°C

Temp. in °C	Density in gm/c.c.	Temp. in °C	Density in gm/c.c.	Temp. in °C	Density in gm/c.c.
0	0·99987	15	0·99913	50	0·98807
2	0·99997	20	0·99823	55	0·98573
4	1·00000	25	0·99707	60	0·98324
6	0·99997	30	0·99567	70	0·97781
8	0·99988	35	0·99406	80	0·97183
10	0·99973	40	0·99224	90	0·96534
12	0·99953	45	0·99025	100	0·95838

6. Yonug's Modulii, Rigidity Modulii and Breaking Stress of Wires

Substance	Y in dynes/cm^2	μ in dynes/cm^2	Approximate Breaking stress in kg/cm^2
Aluminium	$7·05\times10^{11}$	$2·65\times10^{11}$	2000
Brass	$9·7\text{-}10·2\times10^{11}$	$3·5\text{-}3·7\times10^{11}$	3400
Copper	$12·4\text{-}12·9\times10^{11}$	$3·9\text{-}4·0\times10^{11}$	3000
German Silver	$11·6\times10^{11}$	$4·3\text{-}4·7\times10^{11}$	4600
Glass : Crown	$6·5\text{-}7·8\times10^{11}$	$2·6\text{-}3·2\times10^{11}$	500
Iron	$19\text{-}20\times10^{11}$	$7·7\text{-}8·3\times10^{11}$	6000
Steel	$19·5\text{-}20·6\times10^{11}$	$7·9\text{-}8·9\times10^{11}$	8000
Rubber	$0·10\text{-}0·70\times10^{11}$	$0·00016\times10^{11}$	—

7. Viscosities and Surface Tensions

Substance	Temperature	Viscosity in poise	Surface Tension in dynes/cm
Water	0°C	0·01794	75·64
	20°C	0·01002	72·75
	30°C	0·00800	71·18
	40°C	0·00654	69·56
Aniline	15°C	0·0530	43·0
Olive oil	30°C	52	31·0
Castor oil	30°C	451	—

8. Co-efficients of Linear Expansion

(Mean values between 0°C and 100°C)

Aluminium	$22\times10^{-6}/^\circ C$	Glass	$8{\cdot}5\times10^{-6}/^\circ C$
Brass	$19\times10^{-6}/^\circ C$	Silver	$19\times10^{-6}/^\circ C$
Copper	$17\times10^{-6}/^\circ C$		
Cast Iron	$11\times10^{-6}/^\circ C$		
Steel	$11{\cdot}0\times10^{-6}/^\circ C$		

9. Co-efficient of Cubical Expansion of Liquids

(Mean values between 0°C and 40°C)

Aniline	$85\times10^{-5}/^\circ C$	Mercury	$1{\cdot}82\times10^{-5}/^\circ C$
Glycerine	$50\times10^{-5}/^\circ C$	Paraffin oil	$90\times10^{-5}/^\circ C$
Turpentine	$94\times10^{-5}/^\circ C$		

10. Co-efficients of Cubical Expansion of Water in different ranges in Temperatures

5°—10°C	$5{\cdot}3\times10^{-5}/^\circ C$	40°—60°C	$45{\cdot}8\times10^{-5}/^\circ C$
10°—20°C	$15{\cdot}0\times10^{-5}/^\circ C$	60°—80°C	$58{\cdot}7\times10^{-5}/^\circ C$
20°—40°C	$30{\cdot}2\times10^{-5}/^\circ C$	80°—100°C	$43{\cdot}6\times10^{-5}/^\circ C$

Specific Heats of Solids and Liquids

Substance	Specific heat	Substance	Specific heat	Substance	Specific heat
Aluminium	0·212	India Rubber	0·27—0·48	Kerosene oil	0·51-0·54
Brass	0·094	Iron	0·11	Linseed oil	0·44
Common Salt	0·21	Lead	0·031	Mustard oil	0·5
Copper	0·094	Zinc	0·092	Olive oil	0·47
German. Silver	0·095	Aniline	0·51	Turpentine	0·46
Glass	0·19	Glycerine	0·58		

12. Melting Points of Solids

Bee wax	61°–64°C	Paraffin wax	
Napthalene	80°C	Soft	38°–52°C
		Hard	52°–56°C

13. Co-efficients of Thermal Conductivity

[Unit : Cal. cm^{-1} sec^{-1} (deg. C)$^{-1}$]

Aluminium	0·55	Asbestos Cement sheet	0·00070
Brass	0·26	Soda glass	0·0013–0·0018
Copper	0·91	Rubber	0·00035
Lead	0·082		
Steel	0·09		

14. Saturated Aqueous Vapour Pressures at different Temperatures

(in mm of mercury)

Temp. °C	Pressure	Temp. °C	Pressure	Temp. °C	Pressure	Temp. °C	Pressure
10	9·21	18	15·46	26	25·13	34	39·75
11	9·84	19	16·46	27	26·65	35	42·02
12	10·51	20	17·52	28	28·25	36	44·40
13	11·23	21	18·62	29	29·94	37	46·90
14	11·98	22	19·79	30	31·71	38	49·51
15	12·78	23	21·02	31	33·57	39	52·26
16	13·62	24	22·32	32	35·53	40	55·13
17	14·25	25	23·69	33	37·59	50	92·30

15. Refractive Indices

(At $\lambda=5893$ A^{o} of Sodium light)

Substance	Refractive index	Substance	Refractive index
Aniline	1·590	*Glass* :	
Glycerine	1·44	Ordinary crown	1·48–1·54
Kerosene oil	1·44	Dense crown	1·58–1·64
Turpentine	1·47	Ordinary flint	1·53–1·67
Water at 15°C	1·333	Dense flint	1·62–1·92
30°C	1·332		
40°C	1·331		

16. Wavelengths of Gas and Vapour discharge lights

(Line Spectra) (in 10^{-8} cm)

Gas or Vapour	Colour of line	Wave-length	Gas or Vapour	Colour of line	Wave-length
Hydrogen	Red	6562·8	*Argon*	Orange	6059
	Blue	4861·4		Orange	6031
	Blue	4340·4		Yellow	5912
	Violet	4101·9		Yellow	5607
				Green	5452
				Blue	4703
Heilum	Red	7065·2	*Mercury*	Orange	6232·0
	Red	6678·1		Yellow	5790·7
	Yellow	5875·6		Yellow	5769·6
	Green	5047·7		Green	5460·7
	Green	5015·7		Greenish Blue	4959·7
	Greenish Blue	4921·9		Blue	4916·6
	Blue	4713·3		Blue	4358·3
	Blue	4471·5			

17. Velocity of Sound in Gases and Solids

Dry Air at 0°C	331·2 Metres/sec.	Brass	3650 Metres/sec.
Carbondioxide at 0°C	265·8 Metres/sec.	Copper	3970 Metres/sec.
Hydrogen (18°C)	130·1 Metres/sec.	Glass	5140 Metres/sec.

18. Specific Resistance (at 18°C), and Temperature Co-efficients of Resistance (Mean values between 0°C and 100°C)

Subs-tance	Specific Resistance in ohm cm	Temp. Coeff. of Resistance
Aluminium	$2{\cdot}83\times10^{-6}$	$38\times10^{-4}/^{\circ}C$
Brass	$6-9\times10^{-6}$	$10\times10^{-4}/^{\circ}C$
Constantan	49×10^{-6}	$0{\cdot}22\times10^{-4}/^{\circ}C$
Copper	$1{\cdot}74\times16^{-6}$	$42\times10^{-4}/^{\circ}C$

Substance	Specific Resistance in ohm cm	Temp. Coeff. of Resistance
German Silver	$23-33\times10^{-6}$	$2{\cdot}3-6\times10^{-4}/^\circ C$
Iron	12×10^{-6}	$62\times10^{-4}/^\circ C$
Maganin	47×10^{-6}	$0{\cdot}15\times10^{-4}/^\circ C$
Nichrome	110×10^{-6}	$1{\cdot}7\times10^{-4}/^\circ C$
Silver	$1{\cdot}66\times10^{-6}$	$40\times10^{-4}/^\circ C$
Steel	20×10^{-6}	$50\times10^{-4}/^\circ C$

19. Electro-Chemical Equivalents

Copper	0·000329	gm./coulomb
Silver	0·001118	gm./coulomb
Hydrogen	0·0000104	gm./coulomb

20. E. m. f. of Cadmium Cell at the various Temperatures

Temp. in °C	E.M.F. in volts	Temp. in °C	E.M.F. in volts	Temp. in °C	E.M.F. in volts
10	1·0186	22	1·0182	34	1·0175
12	1·0186	24	1·0181	36	1·0174
14	1·0185	26	1·0180	38	1·0173
16	1·0184	28	1·0179	40	1·0171
18	1·0184	30	1·0178		
20	1·0183	32	1·0177		

21. Miscellaneous Physical Constants

Latent Heat of Fusion of ice = 79·7 Cal/gm at 0°C

Latent Heat of Vaporisation of steam = 536 Cal/gm at 100°C

Value of '*g*' at	(i) Patna	$979{\cdot}0$ cm/sec^2
	(ii) Delhi	$979{\cdot}2$ cm/sec^2
	(iii) Calcutta	$978{\cdot}8$ cm/sec^2
	(*iv*) Lucknow	$979{\cdot}4$ cm/sec^2
Value of Dip at	(i) Patna	40°·9
	(ii) Calcutta	29°·9
	(iii) Delhi	41°·0
	(iv) Lucknow	39°·9
Value of H at	(i) Patna	0·361 c.g.s. unit
	(ii) Delhi	0·351
	(iii) Calcutta	0·398
	(iv) Lucknow	0·365

Mean wavelength of sodium light = 5893×10^{-8} cm.

22. Specific Rotation at 20°C for $\lambda = 5893$A°

Cane-sugar in water at conc. (c) 4 to 28 gm/100 gm of solution........ $+66{\cdot}67-0{\cdot}0095$ degree $\times c$

Turpentine pure liquid......... $\doteq -37$ degree.

□□□

22. Tables of Natural Sines, Natural Cosines, Natural Tangents

NATURAL SINES

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences				
	0°·0	0°·1	0°·2	0°·3	0°·4	0°·5	0°·6	0°·7	0°·8	0°·9	1	2	3	4	5
0	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0366	0384	0401	0419	0436	0454	0471	0488	0506	3	6	9	12	15
3	·0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	3	6	9	12	15
4	·0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	3	6	9	12	15
5	·0872	0889	0906	0924	0941	0958	0976	0993	1011	1028	3	6	9	12	14
6	·1045	1063	1080	1097	1115	1132	1149	1167	1184	1201	3	6	9	12	14
7	·1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	3	6	9	12	14
8	·1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	3	6	9	12	14
9	·1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	3	6	9	12	14
10	·1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	3	6	9	12	14
11	·1908	1925	1942	1959	1977	1994	2011	2028	2045	2062	3	6	9	11	14
12	·2079	2096	2113	2130	2147	2164	2181	2198	2215	2232	3	6	9	11	14
13	·2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	3	6	8	11	14
14	·2419	2436	2453	2470	2487	2504	2521	2538	2554	2571	3	6	8	11	14
15	·2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	3	6	8	11	14
16	·2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	3	6	8	11	14
17	·2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	3	6	8	11	14
18	·3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	3	6	8	11	14
19	·3256	3272	3289	3305	3322	3338	3355	3371	3387	3404	3	5	8	11	14
20	·3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	3	5	8	11	14
21	·3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	3	5	8	11	14
22	·3746	3762	3778	3795	3811	3827	3843	3859	3875	3891	3	5	8	11	14
23	·3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	3	5	8	11	14
24	·4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	3	5	8	11	13
25	·4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	3	5	8	11	13
26	·4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	3	5	8	10	13
27	·4540	4555	4571	4586	4602	4617	4633	4648	4664	4679	3	5	8	10	13
28	·4695	4710	4726	4741	4750	4772	4787	4802	4818	4833	3	5	8	10	13
29	·4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	3	5	8	10	13
30	·5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	3	5	8	10	13
31	·5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	2	5	7	10	12
32	·5299	5314	5329	5344	5358	5373	5388	5402	5417	5432	2	5	7	10	12
33	·5446	5461	5476	5490	5505	5519	5534	5548	5563	5577	2	5	7	10	12
34	·5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	2	5	7	10	12
35	·5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	2	5	7	10	12
36	·5878	5892	5906	5920	5934	5948	5962	5976	5990	6004	2	5	7	9	12
37	·6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	2	5	7	9	12
38	·6157	6170	6184	6198	6211	6225	6239	6252	6266	6280	2	5	7	9	11
39	·6293	6307	6320	6334	6347	6361	6374	6388	6401	6414	2	4	7	9	11
40	·6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	2	4	7	9	11
41	·6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	2	4	7	9	11
42	·6691	6704	6717	6730	6743	6756	6769	6782	6794	6807	2	4	6	9	11
43	·6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	2	4	6	8	11
44	·6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	2	4	6	8	10

NATURAL SINES

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences				
											1	2	3	4	5
45	·7071	7083	7096	7108	7120	7133	7145	7157	7169	7181	2	4	6	8	10
46	·7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	2	4	6	8	10
47	·7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2	4	6	8	10
48	·7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2	4	6	8	10
49	·7547	7558	7570	7581	7593	7604	7615	7627	7638	7649	2	4	6	8	9
50	·7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2	4	6	7	9
51	·7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2	4	5	7	9
52	·7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	2	4	5	7	9
53	·7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2	3	5	7	9
54	·8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	2	3	5	7	8
55	·8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2	3	5	7	8
56	·8290	8300	8310	8320	8329	8339	8348	8358	8368	8377	2	3	5	6	8
57	·8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2	3	5	6	8
58	·8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2	3	5	6	8
59	·8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1	3	4	6	7
60	·8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1	3	4	6	7
61	·8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1	3	4	6	7
62	·8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1	3	4	5	7
63	·8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1	3	4	5	6
64	·8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1	3	4	5	6
65	·9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1	2	4	5	6
66	·9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1	2	3	5	6
67	·9205	9212	9219	9225	9232	9239	9245	9252	9259	9265	1	2	3	4	6
68	·9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1	2	3	4	5
69	·9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1	2	3	4	5
70	·9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1	2	3	4	5
71	·9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1	2	3	4	5
72	·9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1	2	3	3	4
73	·9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1	2	2	3	4
74	·9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1	2	2	3	4
75	·9659	9664	9668	9673	9677	9681	9686	9690	9694	9699	1	1	2	3	4
76	·9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	1	1	2	3	3
77	·9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1	1	2	3	3
78	·9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1	1	2	2	3
79	·9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1	1	2	2	3
80	·9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0	1	1	2	2
81	·9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0	1	1	2	2
82	·9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0	1	1	2	2
83	·9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0	1	1	1	2
84	·9945	9947	9949	9951	9952	9954	9956	9957	9959	9960	0	1	1	1	2
85	·9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0	0	1	1	1
86	·9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0	0	1	1	1
87	·9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0	0	0	1	1
88	·9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0	0	0	0	0
89	·9998	9999	9999	9999	9999	1·000	1·000	1·000	1·000	1·000	0	0	0	0	0
90	1·000														

NATURAL COSINES

[*Numbers in difference columns to be subtracted, not added.*]

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences				
											1	2	3	4	5
0	1·000	1·000	1·000	1·000	1·000	1·000	·9999	9999	9999	9999	0	0	0	0	0
1	·9998	9998	9998	9997	9997	9997	9996	9996	9995	9995	0	0	0	0	0
2	·9994	9993	9993	9992	9991	9990	9990	9989	9988	9987	0	0	0	1	1
3	·9986	9985	9984	9983	9982	9981	9980	9979	9978	9977	0	0	1	1	1
4	·9976	9974	9973	9972	9971	9969	9968	9966	9965	9963	0	0	1	1	1
5	·9962	9960	9959	9957	9956	9954	9952	9951	9949	9947	0	1	1	1	2
6	·9945	9943	9942	9940	9938	9936	9934	9932	9930	9928	0	1	1	1	2
7	·9925	9923	9921	9919	9917	9914	9912	9910	9907	9905	0	1	1	2	2
8	·9903	9900	9898	9895	9893	9890	9888	9885	9882	9880	0	1	1	2	2
9	·9877	9874	9871	9869	9866	9863	9860	9857	9854	9851	0	1	1	2	2
10	·9848	9845	9842	9839	9836	9833	9829	9826	9823	9820	1	1	2	2	3
11	·9816	9813	9810	9806	9803	9799	9796	9792	9789	9785	1	1	2	2	3
12	·9781	9778	9774	9770	9767	9763	9759	9755	9751	9748	1	1	2	3	3
13	·9744	9740	9736	9732	9728	9724	9720	9715	9711	9707	1	1	2	3	3
14	·9703	9699	9694	9690	9686	9681	9677	9673	9668	9664	1	1	2	3	4
15	·9659	9655	9650	9646	9641	9636	9632	9627	9622	9617	1	2	2	3	4
16	·9613	9608	9603	9598	9593	9588	9583	9578	9573	9568	1	2	2	3	4
17	·9563	9558	9553	9548	9542	9537	9532	9527	9521	9516	1	2	3	3	4
18	·9511	9505	9500	9494	9489	9483	9478	9472	9466	9461	1	2	3	4	5
19	·9455	9449	9444	9438	9432	9426	9421	9415	9409	9403	1	2	3	4	5
20	·9397	9391	9385	9379	9373	9367	9361	9354	9348	9342	1	2	3	4	5
21	·9336	9330	9323	9317	9311	9304	9298	9291	9285	9278	1	2	3	4	5
22	·9272	9265	9259	9252	9245	9239	9232	9225	9219	9212	1	2	3	4	6
23	·9205	9198	9191	9184	9178	9171	9164	9157	9150	9143	1	2	3	5	6
24	·9135	9128	9121	9114	9107	9100	9092	9085	9078	9070	1	2	4	5	6
25	·9063	9056	9048	9041	9033	9026	9018	9011	9003	8996	1	3	4	5	6
26	·8988	8980	8973	8965	8957	8949	8942	8934	8926	8918	1	3	4	5	6
27	·8910	8902	8894	8886	8878	8870	8862	8854	8846	8838	1	3	4	5	7
28	·8829	8821	8813	8805	8796	8788	8780	8771	8763	8755	1	3	4	6	7
29	·8746	8738	8729	8721	8712	8704	8695	8686	8678	8669	1	3	4	6	7
30	·8660	8652	8643	8634	8625	8616	8607	8599	8590	8581	1	3	4	6	7
31	·8572	8563	8554	8545	8536	8526	8517	8508	8499	8490	2	3	5	6	8
32	·8480	8471	8462	8453	8443	8434	8425	8415	8406	8396	2	3	5	6	8
33	·8387	8377	8368	8358	8348	8339	8329	8320	8310	8300	2	3	5	6	8
34	·8290	8281	8271	8261	8251	8241	8231	8221	8211	8202	2	3	5	7	8
35	·8192	8181	8171	8161	8151	8141	8131	8121	8111	8100	2	3	5	7	8
36	·8090	8080	8070	8059	8049	8039	8028	8018	8007	7997	2	3	5	7	9
37	·7986	7976	7965	7955	7944	7934	7923	7912	7902	7891	2	4	5	7	9
38	·7880	7869	7859	7848	7837	7826	7815	7804	7793	7782	2	4	5	7	9
39	·7771	7760	7749	7738	7727	7716	7705	7694	7683	7672	2	4	6	7	9
40	·7660	7649	7638	7627	7615	7604	7593	7581	7570	7559	2	4	6	8	9
41	·7547	7536	7524	7513	7501	7490	7478	7466	7455	7443	2	4	6	8	10
42	·7431	7420	7408	7396	7385	7373	7361	7349	7337	7325	2	4	6	8	10
43	·7314	7302	7290	7278	7266	7254	7242	7230	7218	7206	2	4	6	8	10
44	·7193	7181	7169	7157	7145	7133	7120	7108	7096	7083	2	4	6	8	10

NATURAL COSINES

[Numbers in difference columns to be subtracted, not added.]

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences				
											1	2	3	4	5
45	·7071	7059	7046	7034	7022	7009	6997	6984	6972	6959	2	4	6	8	10
46	·6947	6934	6921	6909	6896	6884	6871	6858	6845	6833	2	4	6	8	11
47	·6820	6807	6794	6782	6769	6756	6743	6730	6717	6704	2	4	6	9	11
48	·6691	6678	6665	6652	6639	6626	6613	6600	6587	6574	2	4	7	9	11
49	·6561	6547	6534	6521	6508	6494	6481	6468	6455	6441	2	4	7	9	11
50	·6428	6414	6401	6388	6374	6361	6347	6334	6320	6307	2	4	7	9	11
51	·6293	6280	6266	6252	6239	6225	6211	6198	6184	6170	2	5	7	9	11
52	·6157	6143	6129	6115	6101	6088	6074	6060	6046	6032	2	5	7	9	12
53	·6018	6004	5990	5976	5962	5948	5934	5920	5906	5892	2	5	7	9	12
54	·5878	5864	5850	5835	5821	5807	5793	5779	5764	5750	2	5	7	9	12
55	·5736	5721	5707	5693	5678	5664	5650	5635	5621	5606	2	5	7	10	12
56	·5592	5577	5563	5548	5534	5519	5505	5490	5476	5461	2	5	7	10	12
57	·5446	5432	5417	5402	5388	5373	5358	5344	5329	5314	2	5	7	10	12
58	·5299	5284	5270	5255	5240	5225	5210	5195	5180	5165	2	5	7	10	12
59	·5150	5135	5120	5105	5090	5075	5060	5045	5030	5015	3	5	8	10	13
60	·5000	4985	4970	4955	4939	4924	4909	4894	4879	4863	3	5	8	10	13
61	·4848	4833	4818	4802	4787	4772	4756	4741	4726	4710	3	5	8	10	13
62	·4695	4679	4664	4648	4633	4617	4602	4586	4571	4555	3	5	8	10	13
63	·4540	4524	4509	4493	4478	4462	4446	4431	4415	4399	3	5	8	10	13
64	·4384	4368	4352	4337	4321	4305	4289	4274	4258	4242	3	5	8	11	13
65	·4226	4210	4195	4179	4163	4147	4131	4115	4099	4083	3	5	8	11	13
66	·4067	4051	4035	4019	4003	3987	3971	3955	3939	3923	3	5	8	11	14
67	·3907	3891	3875	3859	3843	3827	3811	3795	3778	3762	3	5	8	11	14
68	·3746	3730	3714	3697	3681	3665	3649	3633	3616	3600	3	5	8	11	14
69	·3584	3567	3551	3535	3518	3502	3486	3469	3453	3437	3	5	8	11	14
70	·3420	3404	3387	3371	3355	3338	3322	3305	3289	3272	3	5	8	11	14
71	·3256	3239	3223	3206	3190	3173	3156	3140	3123	3107	3	6	8	11	14
72	·3090	3074	3057	3040	3024	3007	2990	2974	2957	2940	3	6	8	11	14
73	·2924	2907	2890	2874	2857	2840	2823	2807	2790	2773	3	6	8	11	14
74	·2756	2740	2723	2706	2689	2672	2656	2639	2622	2605	3	6	8	11	14
75	·2588	2571	2554	2538	2521	2504	2487	2470	2453	2436	3	6	8	11	14
76	·2419	2402	2385	2368	2351	2334	2317	2300	2284	2267	3	6	8	11	14
77	·2250	2233	2215	2198	2181	2164	2147	2130	2113	2096	3	6	9	11	14
78	·2079	2062	2045	2028	2011	1994	1977	1959	1942	1925	3	6	9	11	14
79	·1908	1891	1874	1857	1840	1822	1805	1788	1771	1754	3	6	9	11	14
80	·1736	1719	1702	1685	1668	1650	1633	1616	1599	1582	3	6	9	12	14
81	·1564	1547	1530	1513	1495	1478	1461	1444	1426	1409	3	6	9	12	14
82	·1392	1374	1357	1340	1323	1305	1288	1271	1253	1236	3	6	9	12	14
83	·1219	1201	1184	1167	1149	1132	1115	1097	1080	1063	3	6	9	12	14
84	·1045	1028	1011	0993	0976	0958	0941	0924	0906	0889	3	6	9	12	14
85	·0872	0854	0837	0819	0802	0785	0767	0750	0732	0715	3	6	9	12	15
86	·0698	0680	0663	0645	0628	0610	0593	0576	0558	0541	3	6	9	12	15
87	·0523	0506	0488	0471	0454	0436	0419	0401	0384	0366	3	6	9	12	15
88	·0349	0332	0314	0297	0279	0262	0244	0227	0209	0192	3	6	9	12	15
89	·0175	0157	0140	0122	0105	0087	0070	0052	0035	0017	3	6	9	12	15
90	·0000														

NATURAL TANGENTS

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1	2	3	4	5
0	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0367	0384	0402	0419	0437	0454	0472	0489	0507	3	6	9	12	15
3	·0524	0542	0559	0577	0594	0612	0629	0647	0664	0682	3	6	9	12	15
4	·0699	0717	0734	0752	0769	0787	0805	0822	0840	0857	3	6	9	12	15
5	·0875	0892	0910	0928	0945	0963	0981	0998	1016	1033	3	6	9	12	15
6	·1051	1069	1086	1104	1122	1139	1157	1175	1192	1210	3	6	9	12	15
7	·1228	1246	1263	1281	1299	1317	1334	1352	1370	1388	3	6	9	12	15
8	·1405	1423	1441	1459	1477	1495	1512	1530	1548	1566	3	6	9	12	15
9	·1584	1602	1620	1638	1655	1673	1691	1709	1727	1745	3	6	9	12	15
10	·1763	1781	1799	1817	1835	1853	1871	1890	1908	1926	3	6	9	12	15
11	·1944	1962	1980	1998	2016	2035	2053	2071	2089	2107	3	6	9	12	15
12	·2126	2144	2162	2180	2199	2217	2235	2254	2272	2290	3	6	9	12	15
13	·2309	2327	2345	2364	2382	2401	2419	2438	2456	2475	3	6	9	12	15
14	·2493	2512	2530	2549	2568	2586	2605	2623	2642	2661	3	6	9	12	16
15	·2679	2698	2717	2736	2754	2773	2792	2811	2830	2849	3	6	9	13	16
16	·2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	3	6	9	13	16
17	·3057	3076	3096	3115	3134	3153	3172	3191	3211	3230	3	6	10	13	16
18	·3249	3269	3288	3307	3327	3346	3365	3385	3404	3424	3	6	10	13	16
19	·3443	3463	3482	3502	3522	3541	3561	3581	3600	3620	3	7	10	13	16
20	·3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	3	7	10	13	17
21	·3839	3859	3879	3899	3919	3939	3959	3979	4000	4020	3	7	10	13	17
22	·4040	4061	4081	4101	4122	4142	4163	4183	4204	4224	3	7	10	14	17
23	·4245	4265	4286	4307	4327	4348	4369	4390	4411	4431	3	7	10	14	17
24	·4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	4	7	11	14	18
25	·4663	4684	4706	4727	4748	4770	4791	4813	4834	4856	4	7	11	14	18
26	·4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	4	7	11	15	18
27	·5095	5117	5139	5161	5184	5206	5228	5250	5272	5295	4	7	11	15	18
28	·5317	5340	5362	5384	5407	5430	5452	5475	5498	5520	4	8	11	15	19
29	·5543	5566	5589	5612	5635	5658	5681	5704	5727	5750	4	8	12	15	19
30	·5774	5797	5820	5844	5867	5890	5914	5938	5961	5985	4	8	12	16	20
31	·6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	4	8	12	16	20
32	·6249	6273	6297	6322	6346	6371	6395	6420	6445	6469	4	8	12	16	20
33	·6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	4	8	13	17	21
34	·6745	6771	6796	6822	6847	6873	6899	6924	6950	6976	4	9	13	17	21
35	·7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	4	9	13	18	22
36	·7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	5	9	14	18	23
37	·7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	5	9	14	18	23
38	·7813	7841	7869	7898	7926	7954	7983	8012	8040	8069	5	9	14	19	24
39	·8098	8127	8156	8185	8214	8243	8273	8302	8332	8361	5	10	15	20	24
40	·8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	5	10	15	20	25
41	·8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	5	10	16	21	26
42	·9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	5	11	16	21	27
43	9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	6	11	17	22	28
44	·9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	6	11	17	23	29

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Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences				
											1	2	3	4	5
45	1·0000	0035	0070	0105	0141	0176	0212	0247	0283	0319					
46	1·0355	0392	0428	0464	0501	0538	0575	0612	0649	0686	6	12	18	24	3
47	1·0724	0761	0799	0837	0875	0913	0951	0990	1028	1067	6	12	18	25	3
48	1·1106	1145	1184	1224	1263	1303	1343	1383	1423	1463	6	13	19	25	3
49	1·1504	1544	1585	1626	1667	1708	1750	1792	1833	1875	7	13	20	27	3
50	1·1918	1960	2002	2045	2088	2131	2174	2218	2261	2305	7	14	21	28	3
51	1·2349	2393	2437	2482	2527	2572	2617	2662	2708	2753	7	14	22	29	3
52	1·2799	2846	2892	2938	2985	3032	3079	3127	3175	3222	8	15	23	30	3
53	1·3270	3319	3367	3416	3465	3514	3564	3613	3663	3713	8	16	24	31	3
54	1·3764	3814	3865	3916	3968	4019	4071	4124	4176	4229	8	16	25	33	4
55	1·4281	4335	4388	4442	4496	4550	4605	4659	4715	4770	9	17	26	34	4
56	1·4826	4882	4938	4994	5051	5108	5166	5224	5282	5340	9	18	27	36	4
57	1·5399	5458	5517	5577	5637	5697	5757	5818	5880	5941	10	19	29	38	4
58	1·6003	6066	6128	6191	6255	6319	6383	6447	6512	6577	10	20	30	40	5
59	1·6643	6709	6775	6842	6909	6977	7045	7113	7182	7251	11	21	32	43	5
60	1·7321	7391	7461	7532	7603	7675	7747	7820	7893	7966	11	23	34	45	5
61	1·8040	8115	8190	8265	8341	8418	8495	8572	8650	8728	12	24	36	48	6
62	1·8807	8887	8967	9047	9128	9210	9292	9375	9458	9542	13	26	38	51	6
63	1·9626	9711	9797	9883	9970	2·0057	2·0145	2·0233	2·0323	2·0413	14	27	41	55	6
64	2·0503	0594	0686	0778	0872	0965	1060	1155	1251	1348	15	29	44	58	7
65	2·1445	1543	1642	1742	1842	1943	2045	2148	2251	2355.	16	31	47	63	7
66	2·2460	2566	2673	2781	2889	2998	3109	3220	3332	3445	17	34	51	68	8
67	2·3559	3673	3789	3906	4023	4142	4262	4383	4504	4627	18	37	55	73	9
68	2·4751	4876	5002	5129	5257	5386	5517	5649	5782	5916	20	40	60	79	9
69	2·6051	6187	6325	6464	6605	6746	6889	7034	7179	7326	22	43	65	87	10
70	2·7475	7625	7776	7929	8083	8239	8397	8556	8716	8878	24	47	71	95	11
71	2·9042	9208	9375	9544	9714	9887	3·0061	3·0237	3·0415	3·0595	26	52	78	104	13
72	3·0777	0961	1146	1334	1524	1716	1910	2106	2305	2506	29	58	87	116	14
73	3·2709	2914	3122	3332	3544	3759	3977	4197	4420	4646	32	64	96	129	16
74	3·4874	5105	5339	5576	5816	6059	6305	6554	6806	7062	36	72	108	144	1
75	3·7321	7583	7848	8118	8391	8667	8947	9232	9520	9812	41	81	122	163	2
76	4·0108	0408	0713	1022	1335	1653	1976	2303	2635	2972	46	93	139	186	2
77	4·3315	3662	4015	4374	4737	5107	5483	5864	6252	6646	53	107	160	213	2
78	4·7046	7453	7867	8288	8716	9152	9594	5·0045	5·0504	5·0970	Mean differences ceas to be sufficient accurate.				
79	5·1446	1929	2422	2924	3435	3955	4486	5026	5578	6140					
80	5·6713	7297	7894	8502	9124	9758	6·0405	6·1066	6·1742	6·2432					
81	6·3138	3859	4596	5350	6122	6912	7720	8548	9395	7·0264					
82	7·1154	2066	3002	3962	4947	5958	6996	8062	9158	8·0285					
83	8·1443	2636	3863	5126	6427	7769	9152	9·0579	9·2052	9·3572					
84	9·5144	9·677	9·845	10·02	10·20	10·39	10·58	10·78	10·99	11·20					
85	11·43	11·66	11·91	12·16	12·43	12·71	13·00	13·30	13·62	13·95					
86	14·30	14·67	15·06	15·46	15·89	16·35	16·83	17·34	17·89	18·46					
87	19·08	19·74	20·45	21·20	22·02	22·90	23·86	24·90	26·03	27·27					
88	28·64	30·14	31·82	33·69	35·80	38·19	40·92	44·07	47·74	52·08					
89	57·29	63·66	71·62	81·85	95·49	114·6	143·2	191·0	286·5	573·0					
90	∞														

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